CHAPTER 5

ENTROPY TRAPPED IN THE BIOSPHERE

5.1 Overview, behind and ahead

Humankind's relation to its supporting biosphere resembles that of an unborn child to its mother's womb. Both are dependent for sustenance upon their surrounding environments, as well as for the disposal of waste materials. And both would perish if these services were withdrawn. This is a crucial lesson of Chapter 4.

There are disanologies that are no less important. The human race obviously is not a living organism. It is not headed toward a time of partition after which it can exist without the biosphere's assistance. And the ministrations it receives from its sustaining environment are not reserved for humankind alone.

The most important difference for present purposes, however, is that a fetus is not capable of self-initiated action inflicting harm upon its containing matrix. In stark contrast, humanity has initiated a profusion of deliberate projects that are inflicting severe damage on the biosphere that supports it. The task of the present chapter is to inventory the damage in question.

With this chapter, our study reaches a point of transition. Previous chapters have laid down the scientific basis of the study, beginning with the thermodynamic concept of entropy in Chapters 1 and 2. Our concern in Chapters 3 and 4 was to see how this concept applies to living organisms, and to the ecosystems in which they participate. Our main resources in this latter endeavor were the biological sciences, especially that of ecology in which the concept of entropy plays an increasingly prominent role.

The transition in the present chapter regards both focus and resources. Up to now, we have been dealing with processes that might occur almost any time since plant life took hold on earth about 444 million years ago. From here onward, our focus narrows to things that have happened within roughly the last 250 years—the time since the onset of the Industrial

Revolution. The resources on which we must rely for guidance, accordingly, shift from those of science to those of history. In particular, we will be drawing from recent work in the history of energy use, the history of technology, and the burgeoning field of environmental history.

5.2 Thermal pollution

In Chapter 4, negentropy sustaining life in the biosphere was divided into three categories: (a) usable energy, (b) material structure, and (c) non-material functional structure. Corresponding to these categories, entropy can take the form of degraded (useless) energy, degraded material structure (e.g., waste material), and degraded non-material structure (e.g., dysfunctional systems). Entropy in each of these forms is becoming increasingly prevalent within the biosphere. Our discussion of this tendency begins with entropy in the form of degraded energy.

When its work potential has been completely expended, energy takes the form of low-grade heat. In the normal course of events, low-grade heat produced within the biosphere is eliminated as black-body radiation.[1] A common example is the heat produced by sunlight on a desert surface which is transmitted back into space at night. If this process is unimpeded, the desert can become quite chilly before the next sunrise.

If its normal discharge is impaired, however, low-grade heat can accumulate in amounts that have significant biological impact. To visualize this, one may think of buildings without air conditioning that get progressively hotter during a summer heat wave, making it progressively more dangerous for people to remain inside. Heat trapped in this fashion is often referred to as thermal pollution.

One type of thermal pollution studied by ecologists is that caused in streams and lakes utilized by electricity generating stations. Water used to cool condensers of power plants can undergo temperature gains of more than 15˚F, which is enough to cause significant changes in aquatic life near its point of discharge.[2] Spawning and egg development of salmon and trout, for instance, occur in lower temperatures than that of catfish and carp, making it difficult for the more delectable game fish to survive in niches incorporating water discharged from power plants.

Another effect of increased water temperature is a decrease in solubility of oxygen, which is needed for the respiration of aquatic animals like fish and for the decomposition of biodegradable wastes. This reinforces the process of eutrophication, which occurs when excessive amounts of nutrients lead to the growth of large quantities of algae and aquatic plants that use up oxygen required by animal species.[3] A further adverse effect of increased water temperature, in conjunction with eutrophication, is to make the water involved less suitable for drinking. Proliferation of certain algae can produce compounds that are toxic to livestock, and the nitrates present in eutophied lakes can also be toxic to human beings.[4]

Thermal pollution of this sort is one form of entropy with deleterious effects on both aquatic and terrestrial populations. Another sort of thermal pollution with adverse effects is known as global warming.

5.3 Global warming: underlying causes

In its current use, the term 'global warming' designates a buildup of low-grade heat in the atmosphere that cannot be discharged into space by black-body radiation. The main cause of this heat concentration is a breakdown of the mechanisms by which heat is normally transferred through the atmosphere. An analogy would be the mechanical failure of a pump emptying water out of a flooded basement. A contributing cause is increasing heat entering the atmosphere as a result of human activity (see section 9.5.) The analogy here would be more water entering the basement as the pump breaks down. In the current case, causes of both sorts seem to be operating simultaneously.

The warming trend in question is taking place in the broad context of incessant temperature fluctuation over the earth's surface. These variations fall within a narrow range of temperatures that must be maintained for life on earth to continue. Recent studies show periodic fluctuations in average temperature over the long run within a range of about 11˚ to 16˚C (52˚ to 61˚F), with glaciations occurring roughly every 100,000 years.[5] The average global temperature presently is about 15˚C, which is a full degree below the high preceding the most recent ice age.

These observations show that there is nothing new about heat building up in the atmosphere. To the contrary, large amounts of atmospheric heat must be retained for the biosphere to remain within a viable temperature range. As with all major changes in environmental circumstances, past periods of high temperature have been accompanied as a matter of course by adaptive changes in many of the ecosystems affected.

From the human perspective, however, there are two aspects of the current warming trend that make it particularly worrisome. One is that it seems to be developing too rapidly to allow time for compensating human adaptation. The other is that the rapidity of this development appears to be a result of human interference with natural climatic processes.

Here is a brief sketch of the processes involved. Global temperature is held within a viable range by a complex system of negative feedback interactions centered around water vapor in the atmosphere and radiation toward and away from the earth's surface. Although details remain elusive, climatologists have begun to understand these interactions in general outline.[6] Low-lying clouds (typically cumulus) reflect sunlight back into space, keeping it from heating up land masses and oceans. High-flying clouds (typically cirrus), on the other hand, absorb large amounts of outgoing heat, keeping it from leaving the atmosphere.

The concerned feedback processes are set in motion when a given sector of the earth's surface becomes abnormally hot. Under such conditions, the proportion of low-lying to high-flying clouds begins to increase, with more of the former to block incoming sunlight and fewer of the latter to impede outward radiation of heat. The net result is a decrease in surface temperature. When the earth's surface cools down, the reverse process takes over. The proportion of low-lying to high-flying clouds decreases, resulting in an increase in surface temperature beneath. Although many other climatic variables are involved, such as humidity, latitude and longitude, and wind currents, a feedback process of this sort seems largely responsible for maintaining the earth's surface temperature within a stable range.

This is the point at which so-called "greenhouse gases" come into the picture. These include methane (CH_4), nitrous oxide (N_2O), and most notably carbon dioxide (CO_2). Although CO_2 has been part of the earth's atmosphere since the beginning of plant life, its recent notoriety is due to the fact that it is emitted in large quantities by internal combustion engines and fossil-fueled power plants. As it turns out, the additional amounts of CO_2 entering the atmosphere as a result of human industry seem to be disrupting the natural feedback loops that maintain the biosphere at a stable temperature.

By itself, atmospheric CO_2 absorbs far less heat than the water vapor at the heart of the negative feedback process described above. By comparison, the amounts of heat retained by CO_2 are negligible over most parts of the infrared (heat) spectrum. In one part of the spectrum (around 15 micrometers) where the absorption effect of water vapor itself is minimal, however, CO_2 takes over as the main heat-retention factor.[7] This extra absorption due to the presence of unusually large amounts of CO_2 causes the air to become warmer, and the warmer air takes up more water vapor in turn. Increasingly high levels of CO_2 thus introduce a positive feedback effect that throws the temperature-regulating mechanisms of the atmosphere increasingly out of balance. Although it works its mischief indirectly, CO_2 released by human consumption of fossil fuel deserves its reputation as a major source of thermal pollution.

On one hand, industrial society's massive consumption of fossil fuel has reached the point of almost doubling the amount of humanly produced low-grade heat the biosphere was called upon to dissipate during pre-industrial times. Details behind this claim will be examined in the following chapter. On the other hand, substances released by industrial processes have upset the natural regulatory mechanisms that govern the return of degraded heat energy to space. In terms of the analogy at the beginning of this section, the basement is getting fuller and the pump is breaking down.

5.4 Global warming: major effects

In the months following hurricane Katrina (August 2005), the attention of the thinking public was focused on the threat of rising sea levels. The dominant image was the devastation of New Orleans, which was already below sea level (about 6 feet on average) before the storm. It is hard to miss the causal links between increasing air temperature, increasing ice-melts in polar regions, and increasing levels of water lapping at costal cities.

Climatologists naturally are interested in establishing correlations between rising surface temperatures and rising ocean levels. Historical records indicate a temperature rise of about one degree C since the beginning of the industrial revolution, accompanied by a rise in sea level of 4 to 9 inches (depending on data source) during the 20 century alone.[8] Although detailed predictions regarding climate are necessarily uncertain (as well as politically sensitive), researchers have tried to extrapolate from existing data with the help of computer models.

An overly optimistic prediction (assuming that greenhouse gas emission is halted immediately) projects a mere 0.5˚ C temperature increase within the present century, accompanied by a rise in sea level of 4 additional inches. A worst-case scenario has global temperature rising 3.5˚C by 2100, causing a rise in sea level of over a foot.[9] Somewhere in between would be enough to inundate various low-lying islands (e.g., the Maldives), and to wipe out several costal cities already below sea level (e.g., San Jose and Long Beach, as well as New Orleans).

The 2005 flooding of New Orleans, of course, was due not only to higher ocean elevation but also to the sheer intensity of the hurricane that breached its levees. As the public was informed afterwards, the levees had not been built to withstand the force that Katrina brought to bear. Another problem spawned by global warming is that the rising ocean temperatures that come with it appear to be causing tropical storms to increase both in frequency and in intensity. Empirical studies by climatologists show that hurricanes in the northern hemisphere have almost doubled in power since 1950, and that category 5 and 4 hurricanes (the successive ratings of Katrina) themselves have become twice as frequent within the last 30 years.[10] Although the issue is still being debated, there seems to be little doubt that global warming is a significant factor behind these increases.

Another concern is the possible effect of global warming upon the system of currents comprising the Gulf Stream that brings temperate weather to Europe. When the warm water of the Gulf Stream reaches the Norwegian Sea, some of its heat is transferred to the colder air. Being more dense, the now cooler water at the top of the circuit falls to the ocean floor, giving impetus to a return current that flows southward and replenishes its heat. Global warming brings higher air temperatures to the northern regions, which hinders the transfer of heat from the ocean. Higher temperatures also hasten glacial melts, making cool water at the top of the circuit less salty and (being less dense) less forceful in its effect upon south-flowing currents. If the continuity of the Gulf Stream were interrupted for these and similar reasons, it would stop conveying warm water up from the equator and could plunge Europe into a mini-ice-age.

An oceanic impact already in progress comes with the effect of water temperature on the photosynthetic algae at the bottom of most marine food webs.[11] This is illustrated by the case of the zooxanthellae that provide tropical coral reefs both coloration and nourishment. When water temperature becomes too high, these microorganisms are separated from their coral hosts which subsequently bleach and begin to die. Inasmuch as coral reefs serve as habitat for millions of species worldwide, their demise puts countless ocean ecosystems in jeopardy.

The vitality of coral reefs and the algae that feed them also depends heavily upon the pH level (relative acidity and alkalinity) of the water they inhabit. Since both coral and photosynthetic organisms like phytoplankton contain calcium carbonate (an alkali), both are threatened by increasing acidity (lowering of pH levels). During recent decades, more and more

CO_2 has passed from the atmosphere into ocean surface waters. This CO_2 causes the pH of the surface to decrease, with the effect that both coral reefs and phytoplankton are literally dissolving.

The atmosphere's increasing burden of CO_2 thus impairs the stability of marine ecosystems in two distinct ways. As a major cause of global warming, it contributes to the starvation of tropical coral reefs. And by being absorbed from the atmosphere, it is driving ocean acidity to levels that neither corals nor their sustaining algae can tolerate.

Global warming may also be responsible for altering the flow of equatorial air currents in ways that are hastening the spread of arid land areas (desertification). This flow begins with the rise of hot air at the equator into the upper atmosphere where it cools and spreads both northward and southward. When it reaches a latitude where it is no longer sustained by upwelling drafts, this cool air drops toward the ground and flows back to the equator where it is warmed once again and continues the loop. Because air tends to gain and lose moisture as it warms and cools, circulation around this loop results in heavy downpours around the equator and desiccating winds at the other end.

This drying effect is a primary cause of subtropical deserts. As a probable result of increasing temperatures at the subtropics, which keep cool air aloft longer, the circulation loops have been extending to latitudes increasingly removed from the equator. Empirical surveys have shown that subtropical climates have expanded about 70 miles in either direction within the last quarter century.[12] This portends a continuing increase in desert land around the globe. Mediterranean countries such as Greece and Spain are currently undergoing this process; and desertification in northern China has reached crisis proportions.[13]

Other threatening effects of global warming include massive food shortages, wide-spread scarcity of fresh water, and major extinctions of biological species. We return to these topics as the discussion continues.

5.5 Degraded material structure: solid wastes

High-grade energy and high-grade structure are both forms of negentropy (Chapter 2). When degraded, both become forms of entropy. Global warming results from an accumulation of low-grade heat energy within the earth's atmosphere. Having looked at various undesirable effects of global warming, we turn now to problems posed by the growing presence in the biosphere of degraded structure.

In Chapter 4, structure was divided into material and non-material (functional). Examples of high-grade material structure range from the very small (e.g., molecular compounds) to the middle-sized (e.g., dams and buildings), up to and beyond the geophysical (e.g., earth's magnetic shield that deflects potentially harmful solar radiation). This section deals with degraded structure of the mid-range sort.

Environmental problems posed by solid wastes are typically approached in terms of volume. Influences such as population growth, proliferation of consumer products, and rising incomes in industrialized countries, have resulted in astounding accumulations of discarded stuff. New York City alone produced about 5 million tons of solid waste in the year 2000, requiring a 9 mile-long convoy of trucks daily to haul it away.[14] Some of this ends up in landfills as far away as Virginia, and some is simply dumped into the ocean. The mouth of the Hudson River is distinguished by over 100 square kilometers of ocean bottom incapable of supporting life.[15]

Solid wastes generated by U.S. municipalities at large around the turn of the millennium totaled over 230 million tons annually, close to one ton per person average.[16] Even larger amounts of solid wastes are generated by industrial processes in this country, estimated to exceed 265 million tons.[17] Of this, between 5 and 10 percent is toxic.

A compilation of statistics like these on a worldwide basis would be sobering, to say the least.[18] A more important dimension of the problem, however, has to do with the ultimate fate of the wastes we are throwing away. Biologically generated structure (biomass in its various forms) by nature is biodegradable. While some kinds take longer than others, biomass eventually is decomposed and its chemicals recycled in the continuing life-process (Chapter 4).

Crude oil itself is no exception, being decomposable by various micro-organisms found in the soil.

The case is otherwise, however, with many products created from oil by human technology. As a rule, products made from plastics and from other polymers like nylon are not biodegradable. The problem with such materials is that their molecules are too large and too tightly bonded together to be broken down by decomposer organisms. Ways have been found of recycling some of these materials in other plastic products. Progress has also been made recently in breaking polystyrenes down by microbial action. But the most common way of breaking these polymers down currently is by incineration, which not only requires outside energy but also releases toxic gases into the atmosphere. When products made of plastic are used up and discarded into the biosphere, accordingly, most of them are likely to remain there indefinitely.

Plastics are being used increasingly in containers and packaging, as well as in the manufacture of a wide range of electronic and other consumer items. Many plastic products, moreover, tend to wear out quickly. And many are expressly designed for one-time use (e.g., disposable diapers). A result is that increasing percentages of wastes thrown out by human society come in forms that are not biodegradable. In 2002, roughly 54 million tons of plastic were produced in North America.[19] Within a few years, a vast majority of the plastic products resulting will have found their way into our oceans and landfills.

The magnitude of the problem is illustrated by a Texas-sized mass of floating plastic debris accumulated by the rotation of the North Pacific Gyre off the coast of California and Mexico. Included in the mass are small pieces of plastic that resemble zooplankton and enter the ocean food chain when consumed by jellyfish. Tens of thousands of sea mammals die annually in the North Pacific alone from the "plastic poisoning" that results. Waterfowl from a majority of species examined worldwide for this impact were found to have indigestible plastic debris in their stomachs.[20] This debris obviously can be passed on to other animals that eat waterfowl without disemboweling them.

The unvarnished fact of the matter is that the enormous accumulations of plastic junk we are discarding into the environment will continue to grow until we stop using plastic products. This inundation of junk consists of entropic matter that the biosphere cannot discharge as low-grade heat. The normal functions of the biosphere will be increasingly impaired as it becomes increasingly impacted with our plastic wastes.

5.6 Breakdown of the ozone layer

Plastic products like those caught in ocean gyres are degraded material solids, and remain solid when broken up into tiny pieces. Material structure comes in liquid and gaseous forms as well. Among structures of a gaseous nature, none is more important to life on earth than the layer of ozone concentrated in the stratosphere at an altitude of about 15-30 kilometers. This crucial structure is being destroyed by our careless release of petrochemical derivatives.

Ozone (O_3) is a slightly bluish oxygen isotope caused by electrical discharge (among other sources), and hence present to some degree wherever electricity is used. At ground level, it constitutes a pollutant that not only makes breathing difficult but reduces plant photosynthesis by about 20 percent.[21] This ozone is obviously undesirable.

However, there is an accumulation of ozone in the stratosphere, built up by the action of sunlight on atmospheric oxygen over hundreds of millions of years, which (until recently) blocked out about 99 percent of incoming ultraviolet (UV) radiation. This ozone is not only desirable, but is literally essential for human life.

In its shortest wavelengths, UV radiation is lethal enough to be used in medicine as a means of sterilization. At midrange frequencies, it causes skin cancer, macular degeneration and cataracts in susceptible humans. Midrange UV can also damage the photosynthetic capacities of plants, harm the eggs and larvae of terrestrial fauna, and destroy plankton near the ocean surface. These plankton are the main source of biomass for marine ecosystems, and account for a large percentage of the biosphere's production of oxygen. So important is the protective role of stratospheric ozone that terrestrial life could not have begun to proliferate until that ozone layer was largely in place.

Ozone breaks down when exposed to halogens like chlorine and bromine.[22] During the ages while the ozone layer was forming, there was no significant presence of these chemicals in the upper atmosphere. Then in the early 1930s, industrial chemists hit upon a class of petroleum products known as chloroflourocarbons (CFCs), of which freon used in air-conditioning is probably the best-known. CFCs were first used as refrigerants and as propellants in spray cans, and subsequently used in the manufacture of electronic circuit boards and of styrofoam products. Since CFCs are relatively cheap to produce, little effort was made to conserve in their use. It is estimated that by 1987 (the date of the Montreal Protocol, the first international agreement limiting their use), about 650 thousand tons of CFC gases had escaped into the upper atmosphere.

Partial destruction of the ozone layer over Antarctica was detected in the late 1970s. By the late 1980s, warnings were being issued in Australia to avoid unnecessary exposure to the sun. "Holes" in the layer over several northern countries were discovered at about the same time, and by the mid 1990s parts of the US were affected as well. It has been estimated that between one and two million additional cases of skin cancer were caused by ozone depletion between 1975 and 2000, which entails between 10 and 20 thousand premature deaths. Despite earlier hopes that the ozone layer had begun to heal as a result of the Montreal Protocol, research results released in 2005 showed that the protective layer over the Artic was the thinnest on record.[23]

A contributing factor undoubtedly is that, although some heavily industrialized countries (USA, Russia, Japan, those of the EU) sharply curtailed their use of CFCs after 1987, others (India and China) continued to increase their use. Even if production of these gases were to stop entirely, depletion of the ozone layer from past use will continue into the second half of the 21st century. No one knows how many centuries it will take for our ozone shield to regain the full protective capacity from which we benefited prior to the invention of CFCs in the early 1930s.

5.7 Degraded functional structure: disrupted cycles of replenishment

Chapter 4 distinguished between material and functional (non-material) structure and between their respective forms of degradation. The preceding sections (5.5 and 5.6) have looked at degraded material structure of two particularly damaging sorts. We turn now to consider several ways in which the functional structure of the biosphere is being impaired. We start with the disruption of certain natural cycles that maintain ingredients essential to life in ready supply.

One such cycle consists of the reciprocity between nitrification (the conversion of free nitrogen to soluble compounds) and denitrification (the conversion of compounds to free nitrogen), which scientists refer to as the nitrogen cycle. The main products of nitrification are ammonium (NH_4) and nitrate (NO_3), which plants assimilate as nutrients. Denitrification occurs as nitrates from dead organic matter are broken down into free nitrogen (N_2) and nitrous oxide (N_20) by the action of certain bacteria. Some of the resulting N_20 is further reduced to N_2 and some usually escapes into the atmosphere.

Although human activity plays a limited role in denitrification (e.g., through sewage treatment), its influence on the nitrification phase of the cycle is much more extensive. Its major contribution in this regard comes with the industrial fixation of nitrogen for use in fertilizers. As a baseline for comparison, about 140 million metric tons of nitrogen per annum is converted into compounds by natural biological processes.[24] Around the turn of the millennium, about 80 million *additional* tons entered the biosphere in the form of commercial fertilizers. Use of commercially produced fertilizers continues to grow, and is projected to reach 134 million tons per annum within another two decades.

Despite salutary effects in alleviating world hunger, this massive infusion of nitrogen compounds into the biosphere has had environmental consequences that are largely negative. One is its substantial contribution to global warming. As a general tendency, the more nitrogen compounds are involved in biological processes, the more nitrous oxide results from denitrification. Nitrous oxide, it turns out, is a heat-trapping gas that absorbs out-going infrared radiation not captured by other greenhouse gases (see section 5.3). By retaining this heat in the atmosphere, nitrous oxide contributes a significant percent of overall greenhouse warming.

Another adverse consequence of industrially fixed nitrogen is its role in the eutrophication of lakes and waterways. As noted in section 5.2, eutrophication occurs when excessive amounts of nutrients find their way into a body of water, accelerating the growth of algae and aquatic plants that consume oxygen needed for animal life. A major cause of this condition currently is the run-off of commercially produced fertilizers from land unprepared to retain them. This condition affects inland and coastal waterways alike. According to an opinion made public recently by a group of prominent biologists,[25] the eutrophication of estuaries and coastal seas is "arguably the most serious human threat to the integrity of coastal ecosystems."

The same group of scientists found a correlation between use of commercial fertilizers and loss of species diversity. New sources of nitrogen lead to the dominance of a few plant species prepared to take advantage of the additional nutrients, enabling them to crowd out their less receptive neighbors. In certain parts of Europe and North America where use of manufactured fertilizers has been particularly intense, the increased dominance of a few nitrogen-responsive grasses has caused decreases in other plant species of up to 80%. We return to the topic of decreasing biodiversity in the final section of this chapter.

Another cycle that must remain in approximate balance for most ecosystems to function is the complex set of interactions by which carbon dioxide (CO_2) is exchanged for oxygen, and vice versa. As previously described in section 4.2, plants absorb CO_2 from the atmosphere (in land-based systems), combine it with water and various other chemicals by photosynthesis, and produce new plant-mass and oxygen as a result. At the other end of the cycle, animals take oxygen from the air, use it in the metabolic reduction of food, and emit the resulting CO_2 back into the atmosphere. While considerable variation in relative levels of these two gases in the atmosphere seems tolerable in the short term, ecosystems involving both plants and animals would suffer from an overbalance in either direction over an extended period.

Several factors are at work today that tend to upset the balance between these two vital gases. One is the rapid growth of land committed to roads and buildings, which decreases the amount of plant life using CO_2 for photosynthesis. Another is the prodigious destruction of the world's vegetation by burning, which not only decreases the overall amount of plant life but also introduces large amounts of CO_2 into the air. As already noted, CO_2 is the greenhouse gas primarily responsible for global warming. The major source of excess CO_2 currently building up in the earth's atmosphere, however, appears to be our profligate use of fossil fuels. Here is one more way in which our addiction to fossil fuel is upsetting the biosphere: it is disrupting the balanced interchange between carbon dioxide and oxygen upon which most plants and animals are vitally dependent.

No less important for a properly functioning biosphere is a steady balance of the water cycle. Of the approximately 1.5 billion cubic kilometers of H_2O on or near the earth's surface, about 97% exists as liquid in seas and oceans. Of the remaining 3%, about three-quarters is frozen in polar ice caps and mountain glaciers, and most of the rest exists in fresh water lakes and underground aquifers.[26] At any given moment, a certain amount of water vapor in the atmosphere condenses as precipitation, and a comparable amount evaporates back into the atmosphere. Average rates of precipitation and evaporation, however, differ widely from place to place. These differential rates play a major role in determining the distribution of various life-forms across the Earth's surface. Let us consider human life in particular.

While human life today can be supported almost anywhere in the biosphere, it is concentrated in ecosystems with a broad basis of photosynthetic productivity (i.e., with ample plant life). Since plant life requires reliable supplies of fresh water (by rainfall or aquifer), this means that the human population by and large is dependent upon a water cycle that makes water available on a regular basis in quantities needed by local plant life. The problem in this regard is that water is becoming increasingly scarce in many parts of the world, to the extent that available sources are no longer adequate to support indigenous human populations. Because of such phenomena as recent droughts in central Africa, receding aquifers in North America, and worldwide pollution of lakes and rivers, large scale imbalances are occurring in those parts of the planet's overall water cycle that affect human existence directly. Another source of imbalance, of course, is the increasing demand for water in various sectors of human industry, such as recreation (e.g., golf courses), mining, and the cooling of electricity generators.

These examples are representative of many such cycles that must remain in equilibrium for the biosphere to remain hospitable to human existence. Major disruptions of these cycles introduce significant disorder within the biosphere. And disorder we have learned to recognize as a form of entropy.

5.8 Industrialized agriculture and the Green Revolution

Human disruption of natural cycles can set forces in motion that lead to ecosystem collapse. There are other circumstances of ecosystem destruction to which humans contribute more directly. A case in point is the production of crops by "factory farming."

The earth's surface includes roughly 22 billion acres capable of supporting vegetation.[27] Of this, about one-sixth is used for the production of crops, as distinct from the grazing of livestock (which occupies an additional one-third). By very nature, agriculture involves the replacement of naturally evolved ecosystems with contrived systems over which humans exercise at least partial control.

In their efforts to gain more complete control, however, food producers in recent decades have turned farming into a manufacturing process largely reliant on sophisticated technology. To begin with, the operation is usually given over to a single crop (monoculture), planted with commercially produced and often genetically engineered seed. The process requires getting rid of competing plant species ("weeds"), which is accomplished by petrochemically produced weed-killers (herbicides). It also requires the eradication of damaging insects, accomplished by dosing the plants and surrounding soil with other kinds of petrochemical poisons (insecticides).

Once these poisons are in the soil, moreover, they kill off microorganisms responsible for converting dead biomass into compounds capable of nourishing new plant life.[28] The infusion of petrochemicals continues with the application of artificial fertilizers, which are now the monocrop's only source of nourishment. In effect, the factory farm is a region removed from the order of nature and converted into a holding ground for the production of food by petrochemical technology.

This is the stuff of which the Green Revolution was made. The Green Revolution was a technological package exported from first-world laboratories to the cultivated fields of the world at large. Plant geneticists isolated strains of staple crops like corn and rice that produced high yields in response to artificial fertilization, were relatively pest-resistant, and could be planted and harvested mechanically. The impressive achievements of the Green Revolution during the 1960s and 1970s have been copiously documented For a while it was widely touted as the technological salvation of an increasingly populous and hungry world.

But it was not long before the flaws inherent in this technological program became apparent. One socioeconomic problem is that developing countries often do not have the funds to pay for the chemical products and machines required. Another is that the monocrops grown in these countries are usually sold abroad to improve cash flow rather than used to feed their own peoples. Yet another is that the production techniques in question encourage large-scale industrial agriculture at the expense of small farmers, who subsequently lose their acreage to large corporations.

From an ecological perspective, however, the most severe problem is that the chemicals and production techniques characteristic of the Green Revolution are destroying the ecosystems by which indigenous people had long been sustained. Wild plants and animals once used for food are being poisoned,[29] local water supplies are being polluted by chemical run-off, and productive wetlands are being drained to accommodate heavy machinery. The quandary faced by the original occupants is that the new way of producing food is too expensive, but that time-tested ways are no longer serviceable.

Looking ahead to the next section, we may note that agribusiness is a significant factor in contemporary loss of biodiversity as well. Whereas humans at one time or another have used perhaps 3,000 species of plants for food, only about 150 of these (1 in 20) are commercially produced today, and most of the rest have gone extinct. Nine basic foods now account for over 3/4ths of world agriculture, with four of these together outweighing all other plants consumed.[30]

Corn provides a typical example. Less than 1/10th of corn varieties grown a century ago are still in production. Over 97% of total corn production is grown with artificial fertilizers and poisons, almost entirely by monoculture. The few remaining varieties are increasingly at risk of being replaced with genetically modified (GM) strains; between 2001 and 2004, the proportion of GM corn produced in the U.S. increased from 25% to 45% .[31] This bodes ill for corn as a food staple if biological threats emerge that genetic engineers are not able to manage.

5.9 Loss of biodiversity and its human consequences

Biodiversity is diversity of biological species. The more species included in a given ecosystem, the greater its level of biodiversity. The biosphere, of course, is the most diverse ecosystem of all. Varying estimates place the number of species worldwide at between 5 and 50 million, of which about one and one-half million are actually known.[32]

Large numbers of species have become extinct since the biosphere's origin, and many others have taken their place. It has been estimated that species extinction during recent geological time occurred at a rate of about one per year. By the end of the 20th century, however, around thirty to fifty thousand extinctions were occurring each year, mostly in tropical rainforests. At this rate, it seems likely that species now are being lost faster than they are being replaced.[33]

Unlike massive extinctions in the past (recall the passing of the dinosaurs mentioned in section 4.2), the loss now underway is due in large part to human activity. Humanity contributes to the downfall of other species in at least three distinct ways. One is by hunting, either for food or exploitation. Passenger pigeons, once among the most populous bird species in the U.S., became extinct late in the 19th century as a result of consumer demand for their flesh and feathers. In like fashion, there is concern among zoologists that demand for ivory currently is driving elephants toward the point of extinction.

Second is the introduction of invasive species, whether by commerce or by individual travel. The case of purple loosestrife was mentioned in section 4.2. Another frequently discussed example is the introduction of Nile perch into Lake Victoria some 50 years ago, for purposes of commercial fishing. Considered one of the world's worst invasive predators, the Nile perch has caused the extermination of two-hundred or more species once native to the lake.[34]

It is the third category of humanly induced extinction, however, that is ecologically most damaging. This comprises the widespread destruction of habitats themselves, as distinct from the destruction of particular occupants of particular ecological niches. A frequently cited illustration is the obliteration of tropical rainforests by logging and burning. Although estimates vary with source and interest, a typical assessment puts the loss at about 60 thousand square miles (roughly the area of New York state) of rainforest a year. With each year's loss of habitat goes the loss of an additional 25 thousand or more biological species.[35]

Other examples abound. To be sure, most of the forms of ecological damage discussed in this chapter carry loss of species among their consequences. Global warming is destroying coral species in the Caribbean (section 5.4). A combination of habitat change (global warming, UV radiation, pollution and overfishing during the past 50 years has cut species diversity in parts of the ocean by up to 50%.[36] And we have already looked at the tendency of industrialized agriculture to reduce the world's store of edible plant species (section 5.8).

Why does humanity's large-scale destruction of other species constitute a problem for humanity itself? Here are a few reasons focused on the rainforests specifically. Before GM crops, human diets derived entirely (sometimes by deliberate cross-breeding) from species found in the wild. At least 4/5ths of the developed world's present diet originated in tropical rainforests.[37] Well over one thousand edible fruits are still present in the rainforests that have not yet found their way to first-world markets. One reason destroying other species constitutes a problem is that loss of biodiversity threatens these additional food sources.

Before the rise of the pharmaceutical industry, for a second example, most cultures relied on medicinal plants for healing. Currently, about ¼ of manufactured medicines derive from rainforest ingredients; and less than one percent of tropical plants have been tested for possible medicinal uses. Another reason species destruction is problematic is that loss of biodiversity cuts back on our sources of new medications.

For a third example, destruction of plant species and of species that consume them threatens the habitats of upper-level consumers; and massive destruction of such species threatens human habitats in particular. Five centuries ago an estimated ten million native people lived in the Amazon rainforest. Today there are less than 200 thousand, due in large part to massive rainforest destruction. Similar loss of habitat has occurred in the subtropics as a result of desertification. Yet another reason destruction of other species constitutes a human problem is that loss of biodiversity leads to a loss of human habitation.

There is a more general answer to the question, however, of which considerations like these serve as mere particular illustrations. This answer has been at hand since the close of the previous chapter. Human beings are the biosphere's top consumers. At this point in human history, the human race depends upon the biosphere at large for its very existence. Most fundamentally, we depend upon the biosphere both for converting solar energy into forms we can assimilate and for getting rid of the entropy we produce in consuming that energy (section 4.8).

Within the past few hundred years, our needs in both respects have increased enormously. In the aftermath of the Industrial Revolution, humankind has become dependent on modes of production and consumption requiring unprecedented amounts of negentropy (energy and structure) to sustain, which at the same time are dependencies producing unprecedented amounts of entropy (waste heat, degraded structure) for the biosphere to expel. In order to provide services of this sort on the level required, the biosphere must maintain its functional stability (section 4.4)

Inasmuch as functional stability and biodiversity go hand in hand (section 4.6), however, it follows that a substantial loss of biodiversity will substantially diminish the biosphere's ability to provide these services. In upshot, humankind's massive destruction of other species has the effect of undermining the ecological support required for human society’s continued existence. The purpose of the next chapter is to examine the history of energy use that has led humankind into this self-destructive predicament.

Notes

1. Counting the beginning of life (about 3.5 billion years ago) to the present as a single day, we can date the onset of industrialization as occurring within the last millisecond or two. This is a very short time for the ills of industrialization to become so dramatically evident as they are today.

2. Celluloid, the first commercially successful plastic, was introduced by its inventor, Alexander Parkes, in 1862.

3. Vaclav Smil, *General Energetics: Energy in the Biosphere and Civilization* (John Wiley & Sons, New York, 1991), p. 101. Subsequent references to this book will occur within parentheses in the test, citing short title and page number. Other books to be referenced in this manner include: Vaclav Smil, *Energy in World History* (Westview Press, Boulder, CO, 1994);

Andrew Goudie, *The Human Impact on the Natural Environment* (The MIT Press, Cambridge, 1981); I.G. Simmons, *Changing the Face of the Earth* (Basil Blackwell, Oxford, 1989); Clive Ponting, *A Green History of the World* (Penguin Books, New York, 1991); J.R. McNeill, *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (W.W. Norton & Company, New York, 2000); and J. Donald Hughes, *An Environmental History of the World: Humankind's Changing Role in the Community of Life* (Routledge, London, 2001).

4. Estimate varying with geographic area. Semipermanent settlements in salmon and whale territories may have included several hundred people.

5. Simmons estimates 12 million calories per diem for early agriculturists, which converts to about 19 billion joules per annum (one calorie is equivalent to about 4.2 joules). This figure has been reduced by a factor of three in the text above, under the assumption that even after farming became prevalent in certain areas the people involved constituted a relatively small proportion of the human population worldwide. Although estimates like Simmons' are based in part on observation of presumably similar farming cultures exiting presently (op. cit., 40, 47-49), they should be understood as approximations at best.

6. A major use of draft animals in the 20th century was for purposes of military logistics. Ponting notes (op. cit., 272) that the British army used 1,200,000 horses during WWI, and that the Germans (despite their mechanized Panzer divisions) used 2,700,000 horses during WWII.

7. See http://www.cumbria-industries.org.uk/gunpowder.htm (accessed February 2009).

8. This despite the construction of the first major hydroelectric plant at Niagara Falls in 1886 (Ponting, *Green History*, 286).

9. As pointed out previously, per capita energy-use estimates for earlier periods are based on extrapolations from comparable present day circumstances. Estimates from the industrial era, on the other hand, come largely from sources recorded during the period in question.

10. Population data for recent centuries are available from many sources. Entries for earlier times are taken from estimates documented in relevant sections above. A graph showing basically the same progression can be found in Goudie, op. cit., 10.

11. Unless noted otherwise, numbers cited in this section are approximations from graphs in Smil, *Energy*, 186-187.

12. Smil, op. cit., 187. Smil's graphs here lump fossil fuels with primary electricity (wind, hydro, tidal, and geothermal), which affect the overall pattern only marginally (Smil, op. cit., 188). One metric ton of oil equivalent equals 45×10^9 joules. It may be noted that Lester Brown, using more recent data, reports in *Eco-Economy* (W.W. Norton & Company, Inc., New York, 2001, p. 112) about 8,000 million oil-equivalent tons for the year 2000.

13. An ecosystem differs from a mere collection of organisms in that its members are related by distinct patterns of functional interaction. These patterns evolve by a process known as ecological succession. Succession generally involves a gradual replacement of fast growing by more slowly growing organisms, along with a growth in complexity of the interactions among these organisms – i.e., growth in functional structure. Ecologists often use the term ‘assembly’ in reference to this process, the sense being that succession amounts to “constructing” or “putting together” functioning ecosystems.

14. According to the “species-energy theory” currently debated among ecologists, increasing amounts of energy available to an ecosystem tend to reduce the breadth of its niches. This tends to increase the numbers of niches and thus to increase the variety of species the system can accommodate. More species within an ecosystem is tantamount to more contenders in the evolutionary process of succession by which the functional structure of an ecosystem is assembled (see previous note 13). For an early exposition of this theory, see D.H. Wright, “Species-energy theory: an extension of species-area theory,” *Oikos* 41, 498-506, 1983.

15. Ponting, op. cit., ch. 16.

16. This is the topic of Bill McKibben’s *The End of Nature* (Anchor Book, New York, 1989).