

9 | *Man and His Environment*

Some Ecological Principles Restated

Time and time again, we have noted that ecological systems, as well as their components, are normally near steady states and in dynamic equilibrium. At one extreme, the amount of heat energy entering earth's atmosphere must equal exactly that radiated back into space, or else the planet would either warm up or cool down. Other physical equilibria are widespread in, for example, the hydrologic cycle and the various other biogeochemical cycles. Within any particular community of organisms, production and respiration ultimately must balance (Figure 9.1); in successional stages, production at first exceeds respiration but eventually the two become equal when soil formation is finished and the climax, steady-state forest is reached. Even the extent and distribution of various nonclimax communities (which have not reached a steady state) presumably are in some sort of equilibrium, which is determined by the frequency of disturbances and destruction of other successional stages as well as the rate of successional change. Similarly, in most natural ecological communities, the rate of energy flow into each trophic level is exactly balanced by the rate of energy flow out of that level. On islands, rates of extinction of old species balance rates of immigration of new ones, with the total number of species on an island remaining relatively constant (even though the composition may change). Likewise, populations that go extinct locally are presumably replaced periodically by colonists from other populations, so that certain species may be viewed as a set of populations

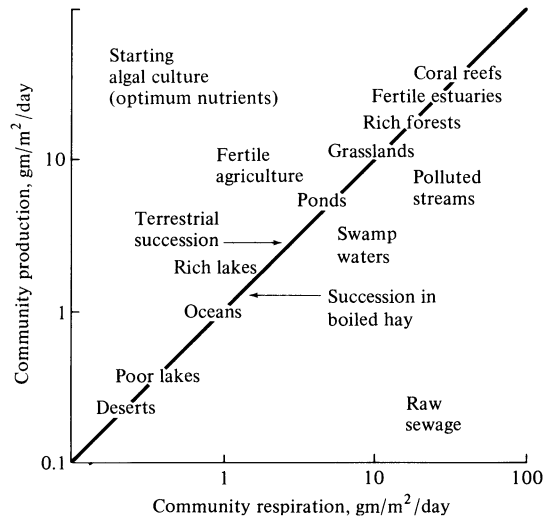


FIGURE 9.1 Total primary production of various communities plotted against the community's total respiration, in grams per square meter per day (proportional to cal/m²/day). Communities along the diagonal line are in equilibrium, with production equal to respiration. Production exceeds respiration (autotrophy) in those above the line, while respiration exceeds production (heterotrophy) in those below the line. [From Odum (1959) after H. T. Odum.]

with local extinctions more or less balanced by inoculations; otherwise such a species would either go extinct or its geographic range would expand indefinitely. Populations of organisms are also usually in some sort of balance, with births equal to deaths; over the long term the average actual rate of increase ultimately must average exactly zero, with the net reproductive rate equal to one, or else a population either overshoots its carrying capacity or declines to extinction. Even pairs of competing, commensal, prey-predator, and host-parasite populations must be in some sort of ecological and evolutionary balance in order to coexist with one another over any period of time. Similarly, any individual organism has a carefully regulated time and energy budget that must balance, with the total amount of energy gathered being equal to the summed amounts spent on various, often conflicting, organismic activities such as growth, maintenance, and reproduction.

Human Population Growth

The above points are obvious and incontestable, yet modern man has largely failed to appreciate their relevance to his own existence. The phenomenal

growth of the human population in the last five centuries (Figure 9.2) is an incredible fact, and one that is rapidly becoming quite perilous. Since the middle ages there has been no decline in population, births have exceeded deaths, the intrinsic rate of increase has always been positive, and the human population has increased exponentially. At the present growth rate, the world population will double in about 35 years, and in some countries current rates will lead to a doubling in only 15 years. This means that only 35 years from now, during the lifetimes of many of us, we could produce enough new people to populate another earth-sized planet to the density of our own globe. However, these new humans would be right here on earth with us. At the time of this writing, there are approximately 4 billion people on earth; even if every couple now in existence were to limit themselves to no more than two children, *effective immediately*, the age distribution of humans contains so many young people that the world population would not stop growing for another 50 to 60 years. What's more, it would stabilize in size at about 9 or 10 billion people, more than twice the current population. This tremendous surge of humanity is a result of the agricultural, industrial, and medical revolutions.

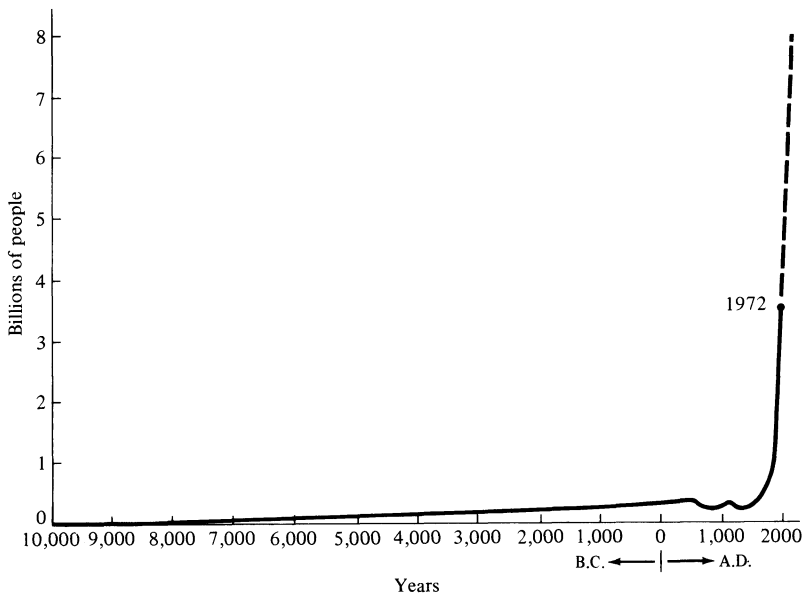


FIGURE 9.2 Estimated size of the human population during the interval from the Pleistocene ice age to present. The dashed line is projected assuming that every couple now in existence limits their reproduction to two offspring, *effective immediately*.

Many students of these matters say that it is already too late to prevent mass starvation and pestilence in many areas, such as China and India. Titles of recent books are indicative: *Standing Room Only*, *The Population Bomb*, and *Famine 1975*. Even now, it is estimated that, on the average, a human starves to death every 3 seconds somewhere in the world. Clearly we are close to or even above carrying capacity in some regions.

Americans still enjoy a fairly high standard of living by most people's criteria. However, gross inequalities both within and between nations can easily and often do generate domestic and international unrest. Five percent of the world's population now consume about 30 percent of earth's non-renewable resources. The underdeveloped countries and the underprivileged are beginning to demand their "share" of these resources and a decent standard of living. A major reason nations have gone to war is that dense populations need more space and other resources. Considering the vast ramifications of war, population pressures are an important root of many of man's problems.

Natural Selection and Man

Homo sapiens is a truly spectacular animal, with an amazing inventiveness and ability to learn and create. A human brain is a beautiful miniature computer with incredible potential. Indeed, technology has been so successful that many think man can accomplish nearly anything he desires. A great deal is already known about the organized reality around us and many of the laws of nature are understood; given time, we could potentially understand much more, including minute details of the intricate workings of our own brains and bodies. We already know much about the very stuff we are made of—matter itself. Man has come a long way both intellectually and culturally in an extremely short period of time, but he is also most impatient. He has subdued natural phenomena and killed or exterminated many organisms in the name of "progress," before either fully appreciating or understanding them. Rapidity of change is concomitant with man's population growth: we are changing our own environment and that of virtually all other organisms at an alarming rate, and one that is steadily accelerating.

The transition from small tribal groups of stone-age cave men in the Pleistocene, living a relatively simple hunting life, to the very complex industrialized world of today has taken place over a period of 10,000 years, or about 500 human generations. All of recorded history includes only 300 generations, and only a hundred generations have lived since the time of

Christ. A mere 25 generations have passed since 1500, the time of the onset of the present surge of human population growth. It appears that we have changed our environment faster than we have been able to adapt to it; we may, in many ways, be partial misfits in our own man-made environment. (Man has, of course, partially adapted to his ever-changing environment by making certain cultural adjustments.)

Man evolved slowly and gradually, with natural selection operating first to adapt him to his relatively simple hunting, and then agrarian, way of life. Certain human emotions and behavior that no doubt had real survival value in these past environments are now dangerously out of place in the context of our present, very different, environment. For instance, revenge must certainly have been adaptive at the level of small bands of men if they were in competition for limited supplies of, say, food, water, or shelter. (Through most of early human history, men cooperated among themselves in small bands which interacted and fought with one another.) Presumably the revenging cave man benefited because others thought twice before infringing on him again. Such actions thus protect one's own interests and they doubtless had clear-cut selective value in the cave, where they were probably programmed into our instinctive behavior over evolutionary time. Our tendency to seek revenge, however, makes little selective sense in high-speed automobiles on our highways or at the level of nuclear warfare. (What *will* we gain from a "second strike" capability?) Yet no one will dispute that such deep-seated revengeful human emotions and behavior are most definitely here.

Exactly analogous considerations hold in reproduction. It is tautological that natural selection has favored the human phenotypes with highest reproductive success. We have thus been programmed to enjoy sex and to want to have children. (Some would argue that such desires are environmentally controlled and culturally manipulatable, but they surely have a genetic component.) Men who leave more successful (that is, breeding) offspring pass proportionately more of their genes into the population gene pool of later generations than do those who leave either fewer or less fit progeny. Thus we are not surprised to find that most people like kids, especially their own, and that they often want to have many children.

Before the agricultural and medical revolutions, human death rates, especially among infants, were high enough to balance birth rates. But now, by killing our own predators and curing our diseases, we have reduced our death rate strikingly, while our birth rate has remained high as would be anticipated from principles of natural selection. As our environment deteriorates around us due to our burgeoning population, we thus find ourselves

victims of natural selection. Man's great intelligence, which has given him both the power to avoid early death and an uncanny ability to inhabit new areas and to exploit new foods and other resources, will be his undoing. We use our brain to try to live outside of many ecological principles; such practices are of necessity temporary. Thus we defeat the pyramid of energy by killing top predators with traps, guns, and dogs, all ecologically unfair tactics in that no other animal has recourse to them, fortunately for us. We have few remaining natural predators, except other men and some parasitic and pathogenic organisms. We live almost anywhere on earth's surface and we eat a vast variety of foods. Man is a very versatile and opportunistic generalist. He exploits resource after resource, and then quickly changes to another as supplies of one are depleted or entirely used up. A prime example is the whaling industry: in the 1930's the largest whales, the blues, were hunted until stocks gave out, then whalers shifted to killing fin whales. After the fin whale population disappeared in the 1960's, the number of sei whales and sperm whales taken have steadily risen. It seems that these species will soon be overexploited as well.

No population's growth rate can continue to remain positive indefinitely in a finite world. Clearly, something is going to have to change. Provided

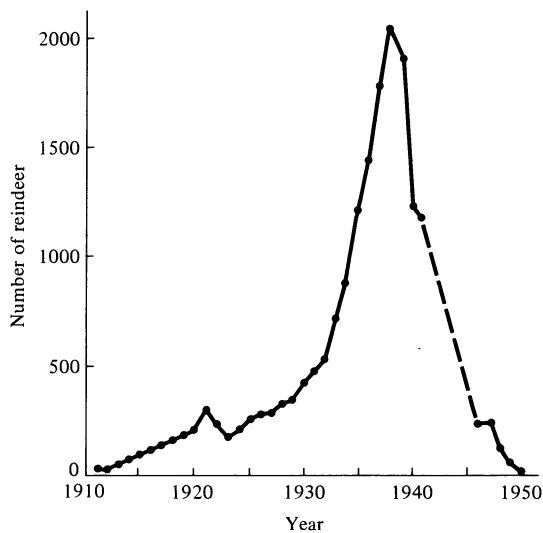


FIGURE 9.3 In 1911, 25 reindeer were introduced on Saint Paul Island in the Pribilofs off Alaska. The population grew rapidly and nearly exponentially until about 1938 when there were over 2000 animals in the 41 square mile island. The reindeer badly overgrazed their food supply (primarily lichens) and the population "crashed." Only 8 animals could be found in 1950. A very similar sequence of events occurred on Saint Matthew Island from 1944 through 1966. [After Krebs (1972) after Scheffer.]

that we do not first annihilate ourselves with nuclear weapons, our population may well eventually crash somewhat as did the reindeer on Saint Paul Island in Alaska (Figure 9.3). Of course, man *could* theoretically stabilize his population at sustainable densities, but it is unlikely that he will. In the event that we do not control our own population, one can only speculate as to what will finally limit the number of men on this globe. Possible limiting factors are numerous, including light, space, heat dissipation, water, pathogens, food, and/or nonrenewable resources. Human populations will probably eventually be limited by several of these factors acting simultaneously.

Selected Ramifications: The Rape of Planet Earth

In the next few pages, I briefly present a few selected examples of man's exploitation of nature, much of which is obvious and/or well known. Informed readers should simply skip to the next section. The most important single point is that the extent of man's consumption, modification, and destruction of resources is directly proportional to human population size. In an overdeveloped country, each citizen places a much greater strain on earth's resources than does each citizen of an underdeveloped country.

For years, the attitude of men has been that earth's resources, including other species, were put here for human use, to be exploited by men, as they most certainly have been. Often we do not even begin to know the full ramifications of what we are doing and yet we proceed at an alarming rate.

As one example, among many, consider the fossil fuels: coal, gas, and oil. It took some 50,000,000 years of primary production to form earth's invaluable coal and oil deposits, yet we will deplete them entirely in less than 1/100,000th of this time (only 500 years); each year we burn up fossil fuel which took *hundreds of thousands* of years to form. As we come closer and closer to completely exhausting these fuels, our rate of consumption skyrockets. Beyond the staggering fact of depletion of this huge and yet irreplaceable natural resource, ramifications of expending so much energy so rapidly have been profound. The smog problem is familiar to everyone. Releasing such vast quantities of carbon dioxide so rapidly has raised the CO₂ content of the upper atmosphere and increased the greenhouse effect (Chapter 2); perhaps this is why, from the late nineteenth century up until about 1940, earth's temperature began to rise, as much as 2°F in places. Fortunately in this case, by sheer accident, the warming trend was reversed in the 1940s, perhaps because enough particulate matter (carbon, soot, etc.) was put into the atmosphere to decrease the amount of

incident solar radiation penetrating the atmosphere, which *so far* has more or less balanced the increased greenhouse effect. No one knows how much longer earth's precarious thermal balance will persist, but it is highly likely that our planet will soon be getting noticeably warmer. Man is tampering with the globe's temperature balance without even knowing or considering the long term consequences. No one knows exactly what effects such overall warming or cooling will have on local climates, but agriculture will almost certainly suffer. A warming of earth could also melt polar ice caps, raise sea levels, and inundate coastal cities.

Regular summer "brown outs" are becoming a familiar occurrence and the impending power shortage has received wide attention. Yet most people are really not very alarmed; they know that before long, certainly by the time we have depleted the supply of fossil fuels, we will be depending on nuclear energy which has virtually no limits. Man is so smart, he can convert matter into energy! (As an aside, I might note that we cannot *eat* atomic energy, although one could, I suppose, imagine using it to power tiers of lights in giant skyscrapers burning 24 hours a day to grow stacks of food crops. Heat dissipation would set a limit on even such a grandiose plan.) However, production of nuclear energy in many ways poses greater problems than burning of coal and oil, since disposing of radioactive wastes with a long half-life is exceedingly difficult. One way to dispose of undesirable pollutants is to inject them deep in the ground; lubrication of faults in Colorado by such means produced earthquakes in an area where they were unknown before. Radioactive wastes are usually encased in concrete and either buried or dropped into the depths of the oceans. Recent proposals to dispose of them in deep salt mines have been severely criticized. No matter what is done with it, much of this radioactive material gets back into circulation. Rainwater leaches out buried wastes and puts it back into our water supplies. Fish hundreds of miles out in the ocean are sometimes highly radioactive. Fallout of strontium and other isotopes from the atmosphere assures that all vegetables grown above ground and all milk, including human mother's milk, are radioactive. Hence, radioactive isotopes from nuclear testing and nuclear reactors already contaminate much of the atmosphere, most of our foods, and our own bodies. We do not yet know all the implications of or the effects of these substances on our own health, although we do know that radioactive materials can cause cancers. A recent proposal to shoot these wastes out into space might actually solve the radioactivity problem for the future, except for that already present in our environment and ourselves. But the ever present thermal problem can not be solved so easily.

Nuclear reactors heat up and must somehow be cooled, usually by a

convenient nearby river. Initially these rivers were allowed to warm up, leading to so-called thermal pollution, that often either changed their fish faunas in undesirable ways or exterminated them entirely. Now, in this age of "ecological awareness," large cooling towers are built which cool the river water back down to a tolerable temperature. The reactor's excess heat, as well as some of the river's water, is given off to the atmosphere. Although much more heat can probably be put into earth's atmosphere, there is a *definite* upper limit on the rate at which heat can be dissipated into the atmosphere and from it into outer space. Thus, cooling towers have not solved the problem of thermal pollution, but have merely postponed it until some later time. Ultimately, the second law of thermodynamics sets the upper limit on how much "waste" heat can be dissipated and therefore sets an upper limit on human use of energy of all sorts.

One of the more tragic, and potentially irreparable, of recent human practices is the massive use of certain pesticides, particularly the chlorinated hydrocarbons such as DDT, DDE, and Dieldrin. Since the 1940s these chemicals have been produced in large amounts and used extensively in agriculture. They provide an inexpensive and very effective means of insect control and were therefore widely acclaimed as a major breakthrough in food production and pest control. Pesticides are sometimes necessary to control mass outbreaks of pests in the traditional agricultural crop of a single plant species, since these simple communities may usually be less stable than more diverse ones with more checks and balances between and among component species (Chapter 7). In a pure stand of its food species, a pest outbreak can rapidly become an epidemic with the pest population growing exponentially. However, some severe problems arise from the use of pesticides. They tend to kill off all insects indiscriminately, including beneficial predatory species and innocuous species like bees and butterflies. Indeed, predatory and parasitic insects are often more susceptible to pesticides than herbivorous pests, which have coevolved with chemical poisons because of the chemical defenses of their plant foods. A pest population that recovers from the effects of an insecticide is frequently freed from its competitors and predators, which allows its population to expand rapidly. The short generation times of most insects allows them to evolve rapidly. Under the very strong selection imposed upon them by lethal pesticides, pest populations have evolved highly resistant strains. Some such resistant strains may have actually evolved enzymes that break down pesticide molecules.

By far the biggest problem with chlorinated hydrocarbons, however, is that these very stable molecules do not disintegrate readily either on their own or by the action of physical factors; moreover, almost all organisms,

including bacteria, have great difficulty in breaking them down. As a result, such pesticides persist and accumulate. These molecules now occur over the entire globe, including the Arctic and the Antarctic (there is even a "DDT belt" in the atmosphere). A terrifying fact is that chlorinated hydrocarbons are *known to interfere with photosynthesis in marine algae* (Wurster, 1968). Paul Ehrlich's essay "Ecocatastrophe" begins with the disruption of oceanic primary production due to chlorinated hydrocarbon interference with phytoplankton photosynthesis. The really frightening thing is that no one can say that Ehrlich's nightmare might not come true! Obviously, it should be illegal to make, let alone use, material with such devastating potential. Even though the United States has greatly reduced its own use of DDT and related chemicals, we still produce them in large amounts and ship them off to other countries. The DDT problem is an international one, for what one country does markedly affects the well-being of distant nations. In spite of all this, the World Health Organization recently recommended continued massive use of these poisons in underdeveloped and overpopulated countries—otherwise, more men would starve and die of malaria.

The solubility properties of the DDT family of molecules make them both highly specific to plants and animals and extremely easily transported. These chemicals are soluble in both water and lipids (fats), but, because they are differentially attracted to the latter, they are concentrated in the tissues of living organisms. Animals at higher trophic levels accumulate more pesticides than those at lower trophic levels because each time a prey item is consumed, most of the pesticide content of the prey is retained in the fatty tissues of the predator. Due to such amplification, concentrations as high as 120 parts per million have been recorded in the fats of some tertiary and quaternary carnivores. Humans are extremely tolerant to DDT and contain high levels of DDT residues; mother's milk, with its high fat content, is especially rich in these poisons. The effects of such retained pesticides are several: animals may simply die from an overdose, as frequently happens after a period of starvation, when fats are mobilized and the poisons released. Subtler effects of pesticide contamination of animals, including man, are little known; they could well be carcinogenic.

Birds are especially vulnerable to the DDT group of pesticides because these substances both mimic estrogen and depress the activity of the enzyme carbonic anhydrase, which plays a critical role in calcium deposition; the ultimate result is a decreased deposition of calcium and a thinning of their eggshells. As a result, there has been a steady decrease in eggshell thickness, and subsequent death of many embryos before hatching, in most predatory bird species since the introduction of DDT (Figure 9.4). Many such species,

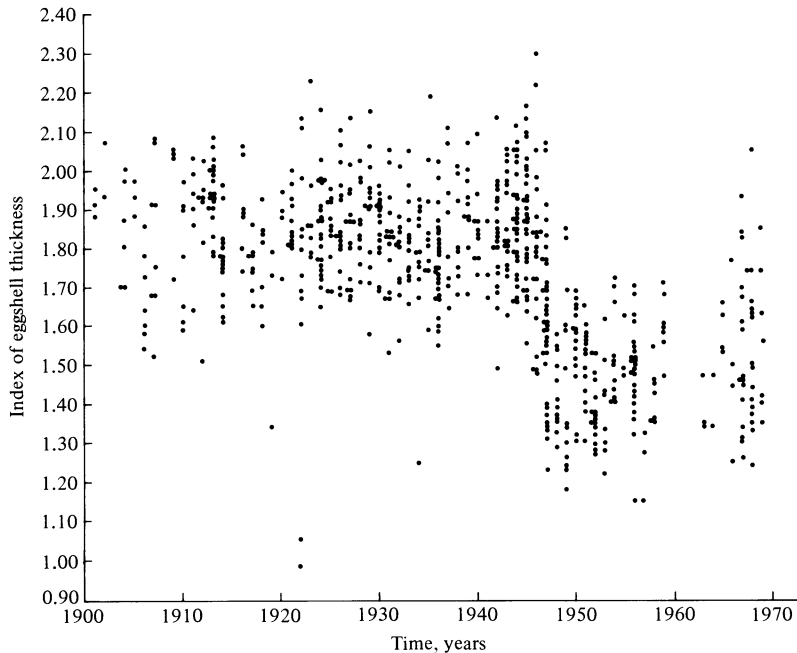


FIGURE 9.4 Plot showing the precipitous decrease in eggshell thickness of peregrine falcons in England after the first widespread use of DDT about 1945. These birds nearly became extinct in the early 1960's, but with reduced use of chlorinated hydrocarbons in Great Britain during this period, the thickness of their eggshells has increased and English peregrine populations seem to be recovering. [After Ratcliffe (1970).]

including the American bald eagle, the brown pelican, the osprey, the Bermuda petrel (a fish-eating sea bird endemic to Bermuda), and the peregrine falcon, have had their reproduction so curtailed that many populations are now in great danger of going extinct. The peregrine, the premier species of falconry, was once found from pole to pole and on all continents, but is now virtually extinct from the mainland U.S. Other populations may soon follow the American birds to extinction.

Man has exterminated hundreds of other species and many more are endangered. Species go extinct naturally during evolutionary time but the alarming thing is the great rapidity and the large number of extinctions due to human interference. What real value is another species? On a practical side, natural game in Africa produce a greater yield in biomass of meat than do domestic cattle and sheep on the same terrain; moreover the native fauna does less damage to the range. It is hardly surprising that species evolutionarily adapted to an area are more efficient at exploiting it. Secondly, the fact that diversity often leads to stability itself suggests that men may someday

have use for a variety of species. Even now, we depend upon genetic variability to breed new and better farm animals and plants. Finally, it takes thousands or millions of years to evolve a species—each is unique and irreplaceable. For many of us, each species has a certain aesthetic value; I greatly enjoy watching a peregrine fly and I deeply regret that a time could come when no one will be able to see this magnificent bird again. To a naturalist and an ecologist, each species has its own particular adaptations that are worthy of study and that may reveal something yet unknown about the organized reality around us.

Another major repercussion of man's expanding population and industrialization concerns his water supply. There is a finite amount of water in the hydrologic cycle. The amount of water evaporated and transpired into the atmosphere sets the limit on how much precipitation can be given up by that same atmosphere. Water that falls on one place, as on the wet side of a mountain, is unavailable for precipitation in another, such as in the rainshadow on the leeward side of the same mountain (indeed, as such dry air falls and warms, it actually extracts water from ecosystems in its path). Man is, of course, very dependent upon the hydrologic cycle. We use huge amounts of water in industry, to grow crops and other foods, for sewage and waste removal, for drinking and bathing, for recreation, and as a power source.

For centuries men have used underground water. With the advent of water pumps, the use of ground water has skyrocketed, and, as a result the water table is falling in many places. Such nonequilibrium use of this water source obviously cannot continue for very long. If we want to continue to use underground water, it must be allowed to replenish itself. Indications are that a severe water shortage is impending. A few estimates of how much water is needed to produce some familiar commodities might underscore how much water each human needs: growing a pound of wheat requires 60 gallons, a pound of rice takes 250 gallons, a quart of milk 1000 gallons, a pound of meat from 2500 to 6000 gallons, and one average automobile about 100,000 gallons. Here again, of course, believers in the omnipotence of technology argue that distillation of sea water will save the day—accompanied, however, by the ever present increase in heat to be dissipated somewhere.

Recall again that a finite amount of water falls on earth's surface and that water used in one place must always come from somewhere else. Men have often gone to extremes to obtain water. Aqueducts and canals have been used for centuries and are still in vogue, with water being moved from an area with an "excess" by human standards to another area with a "deficit."

Such movement of water inevitably alters the hydrologic cycle and earth's weather patterns, however subtly. One neat way to obtain water has been advocated by the U.S. Forest Service in a remarkable pamphlet entitled "More Water by Cutting Trees." Removal of trees and other vegetation from hillsides of a drainage basin allows more water to run off into the creeks and rivers which drain the area, thus providing an increase in surface water for human consumption. However, the same amount of water gained in increased runoff is lost as actual evapotranspiration and therefore is not returned to the atmosphere at that locality. Hence somewhere else precipitation must be decreased, often to the consternation of another party. The city of Buenos Aires, Argentina, provides an example of such weather modification by human tampering with water supplies. Extensive cultivation and irrigation of a formerly arid grassland region immediately west of the city has, in recent years, increased the average annual precipitation by a full five inches. Typically, we modify climate first and then assess its ramifications and implications later.

Another realm of exploitative human activity is land destruction. As pointed out in Chapter 3, soil formation and primary succession take a very long time. Mountains of topsoil that took centuries to form are washed into the oceans annually due to careless man-made erosion. All too often, an area is first denuded of its vegetation by, say, overgrazing, and then much of its soil is lost to erosion. Centuries pass before recovery. Are the short-term gains during one individual's lifetime worth the long-term costs to future men?

As our population burgeons, natural communities are gradually replaced by overgrazed pastures, eroded fields, artificial lakes, golf courses, roads, parking lots, and housing developments. Some natural communities, such as the midwestern tall grass prairie, that once covered many thousands of square miles, have now virtually disappeared. Many other communities are being rapidly destroyed and it is now impossible to find an "undisturbed" natural community. All communities have been contaminated by man-made pesticide molecules and radioisotopes. Natural communities are on their way out. There simply is not room enough for them. This is tragic to ecology and to human knowledge, since so much remains to be both learned and appreciated about natural communities of plants and animals. Moreover, they could well be important to our own survival as well as the quality of life of future men.

Technology and the "Green Revolution"

Believers in the omnipotence of technology dispute much of the preceding and argue that it is technologically possible to support a much larger population of humans on earth. These observers see the plight of people in underdeveloped countries as a failure of technology to fulfill its potential. We have seen that technological "advances," such as DDT and gasoline engines, have proven to be extremely detrimental to our environment; they may ultimately actually *decrease* the maximal sustainable yield. Other aspirations for technological solutions are simply impossible. Thus, it is sometimes suggested that excess people could be shipped off to another planet. Even if Mars were inhabitable *and* we could ship people to that planet, at our present rate of growth we would populate Mars to the density of our own globe in only 35 years; it is energetically impossible to send any significant number of people off into space—they must remain on earth. Indeed, it would be impossible even to redistribute people on earth as needed, using all of our present and planned transportation facilities (Ehrlich and Ehrlich, 1972).

A recent technological breakthrough of considerable importance is the new high-yield grain crops, particularly the so-called miracle wheats and rices, that have started a so-called green revolution. Certainly these crops, coupled with more extensive fertilization, will increase immediate agricultural output and allow us to feed more people (in the long term, overfertilization often decreases maximal sustainable yields). It should be clear, however, that this new potential for food production will only buy us more time (perhaps 15 years) to come to grips with the necessity of population control. To the extent that such technological advances postpone widespread recognition that our population simply cannot continue to grow indefinitely on a finite planet, they are detrimental in the long run even though they are clearly beneficial over a shorter term. The larger we allow our population to become, the more difficult it will be to control it by decreasing birth rates and the more likely it becomes that population control will ultimately be accomplished by increased death rates. Not even technology can allow the human population to grow indefinitely.

Applied and Systems Ecology

We have noted repeatedly that man recognizes the implications, which are often vast and devastating, of his actions only after the fact. Indeed, the