The Climate Problem

There was a time, about 100,000 years ago, when there were just 10,000 people on Earth. A century ago there were 1.5 billion of us, and now there are 6.6 billion. It is estimated that just forty years from now there will be 9 billion. With luck and good management, our population will not grow beyond this point. But some estimates see the number swelling by 1 billion or more in the century after that. That's 10 billion people, on a planet that once held 10,000. Such a burden of human flesh, which all needs to be housed, clothed, and fed, will exacerbate all our environmental woes. Yet who can we ask to get off? The truth is that if we wish to act morally, we can influence population numbers only slowly. So, although it's important to focus on decreasing the population as a long-term solution, we cannot look to it as a solution to the immediate crises.

One problem facing humanity is now so urgent that, unless it is resolved in the next two decades, it

will destroy our global civilization: the climate crisis. The warming trend is real and accelerating, and our pollution is responsible for it. All but the most ignorant, biased, and skeptical now admit this truth, and it's underlined by the findings of the Intergovernmental Panel on Climate Change (IPCC). This body of world experts is painfully conservative, for the members work by consensus and include government representatives from the United States, China, and Saudi Arabia, whose assent is required for every word of every finding. In its *Fourth Assessment Report* (which was published in November 2007), the IPCC blandly stated that the warming trend was "very likely" caused by humans (that means the cause is at least 90 percent certain), and subsequent research has confirmed this, dismissing the idea that sunspots or any other cause proposed by the skeptics could play a role.

The farther into the climate system we try to follow the consequences, the less certain the link with human activity becomes, yet even here great advances are being made. In its *Fourth Assessment Report*, the IPCC thought it only "likely" (66–90 percent certain) that there was a relationship between the warming caused by humans and various changes in Earth's physical and biological systems. In May 2008, however, the largest and most definitive study yet on this subject was published in the world's leading science journal, *Nature*. It announced a clear link between a huge number of changes in the natural world and human-caused warming. The researchers' database included such diverse observations as changes in polar bears' behavior, stream flow, the timing of grape harvests, the flowering time of plants, and bird migration. This study is a landmark in our understanding of just how profoundly we are influencing the very Earth processes that give us life.

As we seek to understand our increasing impact on our planet, it's helpful to think about how we are shuffling matter among the three great organs of Gaia and thereby creating an imbalance. Gaia, the living planet Earth, is like a tree in that it is not alive all the way through. Instead, life is restricted to a thin "rind" that extends seven or eight miles below Earth's surface and about fifteen miles above it. This rind is composed of three great organs: the Earth's crust, air, and water. We must consider how matter flows through these three organs, how they interact, and how life in turn

influences them, if we are to understand our planetary home.

Earth's crust may seem passive—a mere substrate on which life exists—but it is deeply influenced by the presence of life. Today, the energy captured by plants through photosynthesis contributes three times more energy to Earth's overall geochemical cycles (the weathering, burial, and formation of rocks) than geologic activity such as the formation of mountains and volcanism, and in the past this extra energy played an important role in forming the Earth we know. During its first 600 million years (before life arose), Earth had no continents. A remarkable recent study suggests that the extra energy captured by algal and bacterial life led to the development of Earth's continental crust.

How so? All of Earth's original crust was formed from the dark volcanic rock known as basalt, and even today basaltic crust underlies the oceans. Continental crust is formed by the weathering of basalt. Weathering processes separate the lighter elements in the basalt (particularly the silica-rich elements) from the denser ones. These lighter elements, once they have been compressed and heated, form granite, and give rise to the continental crust. Scientists postulate that the vast amount of basalt weathering required to form the continents could have occurred only if algal and bacterial life captured huge amounts of solar energy, some of which was used to manufacture chemicals, such as oxygen and acids, that helped break down the rocks to form sediment. This finding is still debated, but the inference is that without the contributions of early life to the geologic cycle, there would never have been earth beneath our feet.

Earth's crust is dynamic, and its dynamism is particularly vital to life. The continents shift on large "plates," so that every 300 million years or so the plates bearing the continents coalesce, creating an Earth with a single large continent surrounded by sea. Then the plates break apart again, only to come together in another cycle. No one understands precisely what makes Earth's plates move, but the force of gravity, circulation within the molten mantle of the Earth, and the pull of the moon are all thought to exert an influence.

With regard to life, the most important thing about this movement of the plates is its effect on the recycling of minerals and salts. Where plates collide, the

rock underlying one continent is thrust under another and is melted. As a result, mountain ranges and volcanoes are formed, and rivers erode the mineral-rich rocks, creating fresh new soil. This renewal, along with the slow grinding of glaciers, fertilizes life on Earth with the minerals that are essential to plant and animal growth.

Of all the minerals recycled through Earth's crust, carbon is the most critical for this discussion. On planets without life, such as Mars and Venus, the great bulk of the atmosphere is made up of CO_2. On our living planet, in contrast, CO_2 is just a few parts per 10,000 of the atmosphere. The reason for the difference is that over the aeons, enormous quantities of carbon have been drawn into Earth's crust, where today they remain in the form of coal, oil, natural gas and limestone.

If the movement of the plates is important to life on land, it is absolutely vital to life in the sea. The waters of the ocean are recycled, through evaporation and precipitation, through Earth's rivers every 30,000 to 40,000 years, and with each recycling, rivers leach salt from the rocks, which is carried into the sea. You might deduce from this that the oceans are growing saltier. In the nineteenth century this is exactly what scientists thought. Assuming that the oceans were fresh upon their formation, and knowing the rate at which salt was carried into the oceans by rivers, they estimated Earth to be just a few tens of millions of years old, and then coupled this incorrect finding with a belief that a sort of salty doomsday awaited us a few million years hence, when the oceans would have become as salty as the Dead Sea.

The truth is far more remarkable. Earth's oceans have maintained a relatively steady level of saltiness for billions of years, and they do so thanks to the mid-ocean ridges, where Earth's plates are pulled apart, allowing the ocean basins to grow. As the oceanic crust pulls apart, magma comes to the surface and the ocean penetrates this new, hot rock. Hydrothermal vents form, and through these eventually all of the ocean water in the world circulates. It takes 10 million to 100 million years for all the water in the oceans to pass through the hydrothermal vents, but as it does so the chemical structure of the seawater is altered by the extreme heat, and salt is removed. This recycling of the oceans through evaporation, rainfall, and rivers every 40,000 years, and through

the movement of the crust at the mid-ocean ridges every 10 million to 100 million years, keeps the saltiness of the sea constant. It is a remarkable thought that all this is made possible by the continents and their movement—continents that life itself may have helped create.

Earth is the water planet, and water, in its three states—vapor, liquid, and solid—defines and sustains Earth. The principal part of its liquid state forms the second organ of Gaia—the oceans, which cover 71 percent of Earth's surface. Solid water, mostly in the form of glacial ice, covers a further 10.4 percent. Water is essential to life because the various electrochemical processes that constitute humans and other life-forms can occur only within it. The ocean was almost certainly the cradle of life, and it remains life's most expansive habitat. The volume of the oceans—about 330 million cubic miles—is eleven times larger than all the land above the sea. And whereas land is populated by life only at its surface, the entire volume of the oceans is capable of sustaining life.

The oceans are the most important means by which carbon is drawn from the atmosphere. Indeed, when considered on a timescale of centuries, historically they have been the only carbon sink that counts. And today, with more carbon in the air, these sinks have much more to absorb. Some of the carbon absorbed by the ocean is used by algae, and some remains dissolved in the water, where it forms carbolic acid. Some of the carbon taken in by algae falls to the ocean floor when the algae die and sink, and there it is destined to form carbonate rock, thereby removing the carbon more or less permanently from the atmosphere. The carbolic acid that remains in the water, however, is very different. As it builds up, it causes the ocean to acidify; and acidity damages life, including the algae that sequester the carbon. Ocean acidification is a much more urgent threat than we previously thought, and it is most advanced in the north Pacific Ocean.

The north Pacific Ocean is so full of life that it seems like a fantasyland. When I first encountered it, walking along the shore at Tofino near Vancouver in British Columbia, I was awestruck by the drifts of mussel and oyster shells almost as long as my foot, the gigantic barnacles and other oversize sea wrack. Offshore, gray whales abounded within a few yards of the beach, as did seals and killer whales. For me,

coming from a dry and impoverished land, the sheer abundance of life—and titanic life at that—was almost beyond my reckoning.

The unique fecundity of the north Pacific is caused by the same factors that render it exquisitely vulnerable to acidification. The great frozen continent of Antarctica sits at the center of Earth's oceanic system, for much of the deep and intermediate ocean water is exported from its icy fringe. This icy origin dictates that the average temperature of the ocean is a mere 38 degrees Fahrenheit, which is a good thing indeed for life, as frigid water is full of dissolved oxygen and so can support life in the oceans from bottom to top. There is, however, one important exception to this: the north Pacific, which, because of its unique configuration, is the only ocean not cooled and oxygenated by Antarctic waters.

Instead, deep water, depleted of oxygen and rich in CO_2 (and thus acid), wells up here, bringing with it the nutrients that feed the region's oversize life. The result is a fecund ocean, but one where the depth at which organisms can lay down calcareous skeletons is perilously close to the surface. Thus, anything that requires a shell or skeleton has difficulty surviving at depth in the north Pacific. In other oceans, living things can lay down skeletons to a depth of 5,000–8,500 feet, but in the north Pacific they cannot do so below 400–1,800 feet. This is why stony corals, which are found in every other ocean, are absent from the north Pacific. Increasing CO_2 in the atmosphere has already caused a rise in the boundary below which life cannot lay down a skeleton in the north Pacific, to 100–325 feet. Scientists are now warning that in just a few decades, creatures living in the far north Pacific may be unable to lay down skeletons even at the surface. And this would mean an end to all those oysters, mussels, crabs, and lobsters that this fecund ocean yields. Indeed, ultimately it will probably mean an end to the whales and seabirds as well, for without krill, what will they feed upon? And in time, if the problem persists, all the world's oceans will suffer the same fate.

The atmosphere is the smallest, most vulnerable, yet most vital of Earth's organs. To look up into the blue vault of the heavens in an effort to judge its size or importance is profoundly misleading, for the atmosphere appears to stretch on endlessly. Actually, the atmosphere is a gossamer-thin wrapping, insufficient

even to swathe Earth's tallest peaks in breathable air. To get an idea of its actual size, we need to carry out a thought experiment. Imagine compressing the gases of the atmosphere about one-thousandfold—until they become a liquid (this is necessary for a valid comparison). Then imagine comparing the volume of this liquid with that of Earth's oceans. If you could do that, and could see the result, you would discover that the aerial "ocean" is just one five-hundredth the size of Earth's great water oceans. The size of a pollution sink is a prime indicator of its vulnerability. We all know that a small creek or lake is far more likely than a larger one to be damaged by a given volume of pollution—say, sewage. Because the oceans are 500 times larger than the atmosphere, their pollution history has been dramatically different. As we shall soon see, this simple fact will dominate human considerations in the twenty-first century—at least during its first half.

Our shuffling of matter between Gaia's three great organs—crust, air, and water—is at the heart of the problem of climate change. The problem results in large part from digging up the dead—vast amounts of fossilized, once living matter in the form of coal, oil, and natural gas—and burning it. This liberates the ancient carbon that was once in living things, and allows it to reside again in the atmosphere and oceans. Another source of carbon is the destruction of forests and degradation of soils. Since the beginning of the industrial revolution it has added about 200 billion tons of carbon to the atmosphere. The carbon imbalance we have created in these ways is enormous: in just 200 years, the proportion of CO_2 in the atmosphere has risen by around 30 percent—from 2.8 parts per 10,000 to 3.8 parts per 10,000 by 2008. And it is growing. In 2008 the annual carbon emissions of humanity reached 10 billion tons, an amount that caused the concentration of atmospheric CO_2 to increase by 2.2 percent. Not for 55 million years has such an imbalance existed.

A New Dark Age?

In 2006 James Lovelock published a book that bluntly laid before us the consequences of the carbon imbalance. *The Revenge of Gaia* was published in its author's eighty-seventh year, and it is as bleak and penetrating a perspective on human folly in regard to the environment as has ever been written. Lovelock argues that Gaia's climate system is far more sensitive to greenhouse-gas pollution than we imagine, and that the system is already trapped in a vicious circle of positive feedback. "It is almost as if we had lit a fire to keep warm," Lovelock opines, "and failed to notice, as we piled on fuel, that the fire was out of control and the furniture had ignited." Although there is still time to avert a catastrophe, Lovelock believes that humans lack the foresight, wisdom, and political energy required to do so. Instead, he predicts, before the twenty-first century is out our global civilization will have collapsed and a new dark age will have descended on us. Only a few survivors (perhaps just one out of every