DECISION AND DESTINY: THE FUTURE OF LIFE ON EARTH

by George Wald

Man has been engaged, since we have known him, in an unending struggle to know: whence he comes, what kind of thing he is, and at least a hint of what may become of him.

I think that the struggle to know is epitomized in science. One could add a word and say an unending struggle to know God. I think the big question is, If one added that word, would one have changed the meaning of the sentence? For me, no.

I think of myself as a deeply religious person. But my religion is that of one scientist. It is wholly secular. It contains no supernatural elements. Nature is enough for me: enough of mystery, beauty, reality. I am getting along with nature. We are beginning to understand a little about what kind of universe we are in, the place in it of life and the place in life of man. Those are big things. I just want to say a few words about them.

The Universe and Man

We are not alone in this universe. We cannot be. I think we see now that if one begins a universe or any large part of it with just hydrogen, then in many places in it life will arise. Life arises in natural conditions by natural laws; and given enough time in any of those places, one will, I think, have achieved a thinking creature with a technology, like man—somewhat like man. The game of evolution involves two things: to be possible and to be successful. The proof that we are possible is that we are here; and as for our success, we are so successful that we now have the power not only to extinguish mankind but to drag the rest of life on earth along with us. We have become the custodians of life on this planet. All animals and plants live by our sufferance. It is a big responsibility.

As far as I can see, we are not by any means alone in this universe. It is a very big universe—so big that our own galaxy, the Milky Way,

George Wald is professor of biology, Harvard University. This article is an edited transcription of a speech delivered at the John XXIII Institute conference on theology and ecology, Saint Xavier College, Chicago, January 31, 1970.

has the cozy feeling of being just our front yard. Yet that galaxy is almost unimaginably big. It takes light traveling at 186,000 miles a second over one hundred thousand years to cross the Milky Way. There are now about 3.5 billion people on this earth, and we are beginning to feel crowded; but there are one hundred billion stars like our sun in this galaxy, the Milky Way. A simple rule that is easy to remember in these matters of cosmology was stated by Eddington many years ago: 10^{11} stars make a galaxy (that is, one hundred billion; we are just a run-of-the-mill galaxy—they tend to be about that size); 10^{11} galaxies make a universe. The most conservative estimate I have seen of stars in the Milky Way with planets that might bear life is 1 percent. That makes one billion of them just in our own galaxy. They may not all have life, but given enough time they should. And of the one hundred billion galaxies that Eddington was talking about as making a universe, there are already roughly one billion within the range of our most powerful telescopes. One billion is 10^9. There are perhaps 10^9 planetary systems in our own galaxy capable of bearing life, many of which should have life; and there are 10^9 such galaxies already within range of observation; so it makes the fantastically large number of 10^{18} places in our already observed universe that are capable of bearing life.

It is almost unimaginable that in many of those places life must not have started long before it started here. How long before? You think of the pace that we have reached. What our world will be like if we can keep it going one hundred years from now almost transcends our capacities to imagine. But one hundred years is nothing. One thousand years is nothing. In geological time, one million years is just a day. There is no reason that we know of why, on planets elsewhere in our galaxy and in the universe, life should not have gotten going, and should not have gotten to that contemplative creature with a technology, very long before this—a million years, a hundred million years, perhaps even one billion years earlier.

These are hard thoughts. They make one ask the question, What then is our home in the universe? I think our home in the universe is the solar system—our corner of the universe. Let us talk about it a little. It is self-sufficient. Its source of energy is the sun. Relative to that, only negligible amounts of energy come in from the outside. I think the only life in the solar system is that on earth. Everything yet learned from the rockets, from space exploration, everything we have learned, is clinching that conviction: that the only life in the solar system is the life on earth. As for the position of man, I think that we are the only men in

the universe. I have been talking about contemplative creatures who resemble man in their intellectual characteristics and in possessing a technology. But the chance that one of them is a man is negligible.

Man is the result of a long, long evolution, every step of which had a chance, a probability, of happening that way. Compound all those probabilities, and the chance of going through the operation just that way another time in another place is negligible. In fact, if you ask, Is there a chance that elsewhere in the universe there is a vertebrate—one of the great classes of vertebrates that include the fish, the amphibians, the reptiles, the birds, the mammals? I would say it is exceedingly unlikely, an almost negligible probability even for that. That is, if you had the chance to give a competent biologist an advanced creature from some other planet in the universe and let him examine it, the chance that he would say that it is a vertebrate is almost negligible.

So we have our own special individuality. That is true of the creatures here on this planet, including man, but also of the creatures in a reasonably well-inhabited galaxy and universe. And that, of course, raises a series of strange problems. One of them is, Are we ever going to come into contact—even into communication—with some advanced technological civilization in outer space? I myself think the chances are very small. For the distances are almost unimaginably great. If you ask the question, How far would you have to go to reach a sun—a star—that is of the right kind to have perhaps a planet that has a chance of containing life? I would tell you that the nearest one to my knowledge has the beautiful name of Epsilon Eridani—and it is 10.8 light years away. That is, it takes light traveling at 186,000 miles a second 10.8 years to get from us to Epsilon Eridani. That is how long it would take a radio message to travel that distance. And then, if there were someone on Epsilon Eridani to receive it, the proability of which is almost nil—we are asking not just for life, we are asking for someone who can receive radio messages—if there were such a creature, and if he realized that he were getting signals, and if he promptly responded, twenty-two years would have passed between our sending a signal and receiving a response—a long time. It would not make a lively conversation. That is the *nearest* possibility. The others are much farther out.

So are we likely to be visited? There has been all that talk that unidentified flying objects (UFOs) are perhaps visitors from outer space. There are two things against it. First of all, one would have to perform the trick of traveling close to the speed of light. It is hard to do that and not be light. And even that would make a very long journey. There

is another matter that is a little amusing. There are one hundred billion solar systems just in our galaxy. If there even were creatures prepared to travel that way, why should they come here? It is sort of wild. It is like saying there cannot be a man named Swenson in Stockholm because there exist means of transportation; if there were a Swenson in Stockholm, why is he not here? The obvious answer is: Swenson did not choose to come here.

There are other curious questions related to this one. One of them is a theological issue. The old Jahveh, the god of the Hebrews, started as a tribal god. Then he became the god of all people, all nations, all tribes. Now, we have to meet in our minds at least a rather similar issue. That god that became the god of this earth, the god of the people of this earth—is he the god of the universe or is he the god of the solar system? If he is the universal god, you have to begin thinking through your theology in those terms. Is there a Garden of Eden in each of these places? An interesting problem.

Man and the Economy or Ecology of the Planet

Nowadays—in this frankly insane period we are living through, in which many of the men who pose as most practical are clearly the craziest—we are told, relax, relax on all the worries about controlling population and pollution. We are getting ready to move off the earth. There is a lot of real estate out there in the solar system. We will just colonize it. A beautiful thought. But there is no other place in the solar system that is fit for life. There is probably very little elsewhere in the solar system even of high interest to us. Someone said very eloquently—I think it was Lewis Mumford, who, whatever he says, he says eloquently and wisely—there is nothing in the remainder of the solar system as precious as one acre of the earth. The only way we can go around in the solar system is to the degree that we can carry our environment with us. It is a little bit comparable to living at the bottom of the sea. You have to bring your environment along. You are an unwelcome visitor. You can stay only as long as your environment lasts, and then you have to go.

Our planet is about 4.5 billion years old. About three billion years ago, life arose upon it. That was in the cards; it arose spontaneously. There was quite a controversy that disturbed scientists for a couple of centuries between the spontaneous and the supernatural creation of life. And there came a wonderful moment in this bitter controversy in which the champions on both sides were Catholic priests: an Italian

priest, the Abbe Spallanzani, on the one side, insisting upon the impossibility of spontaneous generation, and, on the other side, as the great champion of spontaneous generation, John Turberville Needham, an English Jesuit, the founder and first president of the Belgian Royal Academy. I wondered how a priest could support the theory of spontaneous generation as opposed to its only conceivable alternative, supernatural creation. Needham tells us perfectly plainly that you have only to read the opening paragraphs of the Book of Genesis. The language used, at least in the first story of the creation, is not that God made the living creatures, but that he ordered the earth and waters to bring them forth. "Let the waters bring forth" those living things. "Let the earth bring forth" those living things. Needham's view was that, such orders having once been issued and never, as far as we know, rescinded, the earth and waters were forever free thereafter to bring forth life, which is exactly what we mean by spontaneous generation.

So something like three billion years ago by present evidence, life arose spontaneously, as the culmination of a long succession of processes that began and had been going on since the earth reached its present form, 4.5 billion years ago. It took something like a billion years for the present earth to bring forth life; and once it came forth, it developed according to its own laws, about which I will say a few words shortly. It began its evolution. Evolution is itself an orderly process. It is part of the order of nature. And there came a point in that evolution in which living organisms that had not begun that way, developed—invented, if you wish—the process of photosynthesis. That was a big thing. It is the process by which, using the energy of sunlight, living organisms begin to make organic molecules, that is, those special molecules made of four elements. There are ninety-two natural elements, but 99 percent of the living parts of living organisms here, and I think everywhere in the universe, are made of four of those four elements: hydrogen, carbon, nitrogen, and oxygen. It is the molecules made of those four elements that have been called, since one first recognized them, "organic." Why? Because one generally finds them in organisms. Over ages of time, perhaps a billion years, such organic molecules formed in the high atmosphere and collected in the sea. About three billion years ago, a collection of them reached the point that we might be willing to concede as being alive.

But that was on a different earth from the one we have now. Its atmosphere contained practically no free oxygen—an atmosphere altogether different from our own—and that is worth thinking about. The

first organisms not only were formed from, but relied for their existence entirely upon, the accumulation of organic molecules that had formed during the first billion to 1.5 billion years of the earth's existence. But that is a losing game, just as our use of fossil fuels is a losing game. We are now using up the accumulation of ages of coal and oil. The first organisms had been using up the accumulation of previous ages of organic molecules. Eventually, they would have consumed all those organic molecules, and that would have been the end of life. One would have had to begin the whole process over again. But fortunately, before that happened, photosynthesis had been invented. Photosynthesis is a way in which living organisms can use the energy of sunlight to make new organic molecules. It rendered them independent of their history, of the earlier accumulation of organic molecules. It did one other thing. It began to throw oxygen into the atmosphere for the first time. Now, I want to tell you a little about that.

The whole existence of life on this planet is a tender thing. One does not sufficiently realize to what degree the physical environment in which life exists on this planet is an environment that life itself provided and keeps in being. Even experienced biologists tend to think of the environment as the thing given, the thing that is fixed. It seems that the environment plays the tune, to which living organisms either dance, or die. But it really is not that way at all. Some of the most important features of our environment are themselves the work of living organisms. That is the way it is with the oxygen in our atmosphere. As far as we know, there was no oxygen in our atmosphere until it was put there by living organisms through the process of photosynthesis, performed by plants. And right now, all the oxygen in our atmosphere passes in and out of living organisms and is completely renewed every two thousand years. Two thousand years is just a moment in geological time. It is even worse with carbon dioxide. Every molecule of carbon dioxide, not only in our atmosphere but dissolved in all the waters of the earth, goes in and out of living organisms and is entirely renewed every three hundred years. Something even more surprising is that every molecule of water on the earth, all the water in the seas and the fresh waters of the earth, goes in and out of living organisms and is completely renewed every two million years, just a moment in geological time. We have had men that long on the earth.

Life is a big thing. It is the big adventure of our earth. It has transformed the planet.

Please understand what I am saying. If life were to leave the earth,

the oxygen would leave the atmosphere again. It is life that holds it there—the only thing that holds it there. It is a delicate condition. Another surprise: when we think of photosynthesis, we think of flowering plants and trees. That is just because they are so familiar to us. Something close to 90 percent of all the photosynthesis on earth is done in the upper layers of the ocean, performed by so-called algae. They photosynthesize just like the higher plants. Pollute the ocean waters enough, and you will have to do without something more than fish on Friday.

So we have the best of reasons to be interested in pollution. Our survival depends on keeping that tender state of the relationship of life with the environment in something like its present condition. That was established a long time ago. It must have reached some kind of steady state perhaps a billion years ago. But now we are threatening it very seriously.

The Pollution Problem as Part of a Package

We have, we Americans, a way of going at things hard, making fads of them. The fad for this spring is the environment and pollution. The kids are being turned loose on it, and are turning themselves loose on it. I am happy about that.

But there are two traps concealed in this situation. One is that it is part of a package of issues. It must not become, as many interested persons must at this point hope it will, a distraction from our other issues. There is a whole package of things that need doing. We have to stop that Vietnam war. But there are a lot of other issues, and the kids need to work on the package and so do we. The second trap—and it is true of many other things—is that antipollution must not simply become the new big industry. You see, the American economy has reached a surprising state, a sort of living by taking in its own wash, or perhaps we are taking in the wash for it, we tax-paying citizens. It would be the easiest thing in the world right now to go right on doing the polluting as one business and just superimposing on this a big new multibillion-dollar antipollution business. One could very easily go on now with industry polluting as before, superimposing on it another huge business of antipollution. In these days of conglomerates, it would probably be the same business—one division polluting and another division cleaning up.

A politician spoke of the environment as a "motherhood issue." What he meant was, everybody is for the environment, just as they are for motherhood. Every politician in the country will be glad to rise to the

rostrum and give a ringing and eloquent speech against pollution. But when it comes to particular cases, they are a little more hesitant. One of our biggest polluters is the motor car. That confronts one with the motor car industry and the oil industry. Then there are all those cans and containers and bottles. There are the lumber and power industries. Coping with pollution is not going to be easy. It will involve some pretty large and powerful interests, and one has to be ready for that. So when the politicians have finished on the motherhood aspects of pollution, just ask them what they intend to do right now because it has to be done now. What I was saying about the trap of not making a new and separate industry of depollution is that we shall have to tackle this at its source, to stop the pollution at its source.

We have so many problems to face at once. John Platt at Ann Arbor speaks of the time that we are living in now as a *crisis of crises*.[1] The deeper you go into the crises, the more poignantly you realize what a vast set of problems we are up against—because it is not just one thing, or two, or even three things, but a whole galaxy of absolutely shattering problems, all of them coming to the point of crisis, threatening the whole human enterprise within the next fifteen to at most thirty years—all coming on us together—and we are going to have to do that hardest of things and stop thinking in terms of either this or that and begin to deal with a whole complex of issues. And they all hang together, so that one has to deal with them as a package.

Dealing with Life: Technological and Biological Design

It is rather important—as you try to understand the kind of world we are in and what life is about and what man is about—to realize something else. As one looks about in this world, one sees evidence of design all about one. But two kinds of designs, technological design and biological or organic design, are entirely different processes, the one almost the reverse of the other. They are being confused all the time.

Technological design begins with specifications. You set down the specifications and then try to realize them the best you can. But biological design is an altogether different process. There are no specifications. It is the process that Charles Darwin described a little over a century ago and called natural selection. It has three components—first of all, a constant outpouring of variations. The second variation is a mechanism of inheritance—and that can be either biological, genetic inheritance or, in any animal or human society, learned behavior or cultural inheritance. It takes very careful, rigorous examination in par-

ticular instances to know which of these you are dealing with. I say that because the one works so much like the other.

So first, we have the outpouring of variations; second, the mechanism of inheritance; and now third, the selective principle, a competitive principle—what Darwin called the struggle for existence—in which the organisms, possessing all the inheritable variations, compete with one another. The outcome Darwin spoke of as the "survival of the fittest."

It is a system of constant experimentation in which those variations that prove to work a little better survive; and those variations that work a little less well decay and vanish. This highly experimental process of natural selection at first sight seems awfully slow, wasteful, and inefficient. But we should think well of it, since it has made all the living organisms we know, including man; and the simplest of living organisms is a far more delicately constituted, better adapted, more efficient, and—to use a present-day value—highly miniaturized thing than the most complex of technological devices.

It is very important to sort out the difference between technological design and biological design, which is what we are dealing with in life—but, more than in simply biological life. Charles Darwin realized that in natural selection he had put his finger on a universal principle; and in his book *The Descent of Man* he did not hesitate to apply this to human society, politics, and social problems, to human aesthetics, to ethics, to the conflict and competition of cultures and nations.

I should like to give you an example of natural selection operating in the social sphere. The English in their wisdom never wrote a constitution. There is no written English constitution. The founders of this country, beginning a new nation, facing a wilderness, wrote a constitution. It has made a lot of trouble since. We inherited the great structure of our law from the English, and the heart of it, the heart of our own as well as the English law, is the great system of the so-called common law. That is a biological kind of construction or design, a system of tradition and precedent, that arose by constant trial and error over centuries of experimentation. What does the lawyer study when he studies the common law? Not a code; he studies cases. He studies precedents. Those are the things he cites for the judge when pleading a case. That is biological construction as opposed to such a technological construct as the *code napoléon* or indeed any legal code that one sits down and writes out to fit specifications.

Let me give you another example. I think the fullest embodiment of natural selection in the political sphere is democracy. And the indis-

pensable element in democracy is open-endedness. It is a constant experimentation, so that we cannot predict what our governmental system will be like or be working like in the future. We work it out by trial and error, by keeping those procedures that are found to work better and letting those things lapse that work less well. That is the way we tried and subsequently got rid of prohibition. There are many other instances of the same principle. And, provided we can make it work, I would take my chances on democracy any time, in preference to any such technological construct as so greatly captivated my generation when we were much younger—the planned society, the society constructed to specifications, however brilliantly planned and however benign its intentions.

I should like to say a third thing about biological design. Uniformity offers evolution nothing. Uniformity is the death of evolution. Evolution requires a constant outpouring of variations. That is as true of institutions as it is of individuals. The whole game is the constant outpouring of variations, among which those things that are found to work better are constantly selected. All development depends upon that.

That is the best argument I know for tolerance—but it is something much bigger and better than tolerance. Tolerance is only a negative putting up with variation. What I am saying to you is that differences —physical and social and political—represent one of the greatest positive values in life. We need those variations. They are the most precious things we have. And that goes, as I said, not only for individuals but for institutions. So regard them as precious, value them. All further evolution depends on them.

The Population Problem and the Quality of Human Life

I cannot stop and live with myself afterward without talking about population. You see, there is no problem you can now approach and hope to get somewhere with without coupling it with population control. I cannot think of one. I suppose that man is the first living species, animal or plant, on this planet that has ever been threatened by its own reproductive success.

We have Darwin's phrase, the survival of the fittest. Biologists, who like to measure everything they can, long ago began measuring fitness; and the measure of fitness they have been using for generations is reproductive success. We say that that line of organisms is most fit which produces the largest number of surviving offspring that reach

sexual maturity and themselves reproduce. Yet the whole human enterprise is now threatened by human reproductive success.

The facts are simple enough. By all present indications, our present world population, which I think is already too big, will double by the end of the century. Probably long before that, famine on an unprecedented scale will be facing us in many parts of the world.

But famine is not the heart of the problem. That is the first thing I want to be sure I have said. We have been talking about population control for a long time; but there are a few harsh realities that we are just beginning to appreciate. One of them is not to recognize as the heart of the problem the number of people you could feed to keep alive on the surface of the earth. Just try and have a concept of what the human enterprise is about, of what man is about (that is, what religion is about), and you will realize the utter bankruptcy and inhumanity of turning the human enterprise into such an exercise in production. My heavens, if you really want to hear horrifying things said, go to the experts. They fall in love with their subjects. I read an essay by a famous demographer who said, "What are people growing so excited about? With proper management, we can support a population of 40 billion people on the earth." "Of course," he went on to say, "they wouldn't eat meat. There would be no room for cows on that kind of earth. But we will keep them alive."

What bankruptcy! If that were the problem, we would not right now have to worry so much. In the last ten years the world's food resources have actually increased a little faster than the world's population. That is nothing to be happy about because that is not the essential problem. The essential problem is the quality and meaning of human life; and from that point of view, we are almost surely already overpopulated.

There is another trap in this kind of discussion. That involves the thought that it is the poor of the earth who are making the problem. There was the thought, how terrible, that it is the poorer elements of our American population who have the most children. The well-to-do have fewer children; so clearly, the American strain of *Homo sapiens* is degenerating at a rapid pace because it is taken to be self-evident that being well-to-do is a sign of being a superior animal and being poor an inferior animal. That is the way this has been talked about. But lately, the people who are most deeply concerned with these matters have begun to see that there is much more to say about this. It is precisely the children of the well-to-do who make the most

trouble. They make the biggest demands on the world's resources, and they are the biggest polluters. You can put that on a national basis. An American child, on the average, uses up fifty times as much of the world's resources as an Indian child. We have one-sixth of the population of the earth, and we are using up 40 percent of the irreplaceable natural resources and doing 50 percent of the world's industrial pollution. So just realize that controlling the poor is not the problem. It is controlling the affluent that is the main problem.

And what are we to do? We do not have much time. We have already lost a good part of the game. But let me say it plainly, quickly, and simply, and, perhaps to some of you, shockingly. I think that as rapidly as possible, not merely cheap, but preferably free, safe, and convenient, means of birth control must be made universally available—all over the world. I think that as rapidly as possible, cheap—preferably free—and safe, and convenient, and altogether legal means of abortion have to be made available all over the world. The ideal that I would aim at achieving as quickly as possible is that nowhere on the earth should a woman have an unwanted child. Will that be enough? Let us get there and see. And if that is not enough, then we will have to do other reasonable and sensible things until we have brought population under control. I say those things precisely because of a deep commitment to humanity and to the human enterprise, precisely because I want it to survive, and develop further, and flourish, and acquire much deeper meaning than it has ever achieved before. And I say them, too, precisely through a deep love of and concern for children. One does no child a favor in permitting it to be born unwanted.

Those of you who find the thought of universal abortion difficult, think of the way we do things now, the way we are limiting population now. It is children who are the first victims. We are limiting population now principally through infant mortality. What is killing those children is war, disease, poverty, and famine. We are turning the Four Horsemen of the Apocalypse loose upon the children of the earth. If you think that represents a more moral position, I should like it explained to me.

I want to say another thing that may shock those of you who take the Roman Catholic position. It is not as though one were proposing to begin practicing abortion in a world that was not already doing so. The statistics that I am about to cite are very surprising. They come out of a recent study by a member of the United States Public Health Service.[2] Women are already performing abortions or having them

performed for them—and most of all in the Roman Catholic countries in which other means of birth control are not available. It is now estimated that in France at present there is one abortion per live birth and that throughout Latin America as a whole there is one abortion for every two live births. It goes up and down from one Latin American country to another. In Uruguay we are told that there are now three abortions for every live birth. And those abortions are being performed on the sly, brutally, badly, with great danger to the woman; yet such is their desperation that that is the way it is.

NOTES

1. John Platt, "What We Must Do," *Science* 166 (1969):1115–21.
2. Alice S. Rossi, "Abortion and Social Change," *Dissent* 16 (1969):338–46.