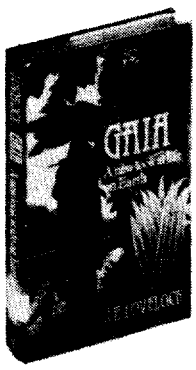
Is Nature Really Motherly?

by W. Ford Doolittle

The Gaia Hypothesis says that Earth's biosphere is in effect one organism. How does a species of one evolve? There's nothing for natural selection to select among.



Gaia: A New Look at Life on Earth
by J.E. Lovelock
Oxford University Press
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THE GOOD THING about this engaging little book by Jim Lovelock is that reading it gives one a warm, comforting feeling about Nature and man's place in it. The bad thing is that this feeling is based on a view of natural selection – that force which alone is responsible for the existence and characteristics of the biosphere – which is unquestionably false. And that is discomforting, because the book is written for a lay readership which may be misled about the extent to which the biosphere can be safely abused, and because the hypothesis it presents has been accepted as daring but tenable by otherwise rational reviewers of popular scientific literature[1]. I will try to present Lovelock's ideas in the same appealing and forceful way in which he presents them, and then show why these ideas are inconsistent with everything we now think we know about the evolutionary process, and embody a kind of logical fallacy for which I am sure logicians must have a name.

Lovelock seeks to explain why conditions on Earth (in particular, its surface temperature, and the chemical compositions of its atmosphere and oceans) differ so dramatically from those on its dead neighbors Venus and Mars. He seeks to explain how these peculiar conditions, which are essential for the survival of life as we know or can imagine it, have never, in the three to four billion years since life began, altered so drastically as to destroy all life. And there are indeed many wonderful things which seem to *demand* explanation.

(1) The average surface temperature of the earth has been maintained, Lovelock claims, at between ten and twenty degrees centigrade for more than three billion years. This in spite of the fact that energy input from the sun has increased some thirty percent during that period and lethal global temperatures well below or above those at which water either freezes or boils might easily have prevailed at various times during the Earth's history.

(2) By extrapolation from the atmospheric compositions of Venus and Mars, one would expect an earthly atmosphere of some 98 percent carbon dioxide, 2 percent nitrogen and only traces of oxygen, which would not support complex forms of life. Instead, we find only 0.03 percent carbon dioxide, 79 percent nitrogen and 21 percent oxygen. These concentrations, as well as those of trace gases such as methane, nitrous oxide and ammonia, differ by many orders of magnitude from equilibrium concentrations calculated from the known rates of chemical reactions between various atmospheric components. The atmosphere is somehow maintained in a chemically most improbable state of disequilibrium.

(3) Each atmospheric gas can be assigned a life-supporting function, and is present in optimal concentration. Carbon dioxide is required for photosynthesis and all life ultimately depends upon it, but if it were present in significantly higher concentrations, a devastating "greenhouse" effect would be produced. Nitrogen serves to

1. See Kenneth Mellanby, New Scientist, October 4, 1979; René Dubos, Nature, November 8, 1979; Phillip Morrison, Scientific American, March 1980.

dilute oxygen, a dangerously flammable gas, and is the primary maintainer of atmospheric pressure. Oxygen is essential for respiration, and thus all animal life, and its present concentration of 21 percent seems optimal, just neatly below that at which even wet wood burns and forest fires would never self-extinguish. Lovelock presents data showing that if oxygen concentrations were to rise to above 25 percent "very little of our present land vegetation could survive the raging conflagration which would destroy tropical rain forests and arctic tundra alike." Oxygen levels are kept high, but below this critical point, by reactions with other atmospheric gases such as methane, of which some one billion tons are produced annually by bacterial activity, and nitrous oxide, also a biological product. Nitrous oxide is implicated as well in the regulation of stratospheric ozone concentration. So is methyl chloride, another biologically produced gas. Ammonia is significant in controlling oceanic acidity and may have, during the early history of the Earth when the Sun was cooler, kept Earth warm enough to support early life, because it, like carbon dioxide, exerts a greenhouse effect.

(4) The annual input (from the land) of salt into the sea is about 540 million tons. At this rate, it should take a scant 80 million years to achieve the present level of salinity (3.4 percent). The oceans are some 400 times older than that, and one should wonder not why the sea is salt, but why it is not concentrated brine. In fact, the oceans seem to have maintained something like their current level of salinity throughout much of their history, and it is very fortunate for life that they have. Salinities of as little as six percent are lethal to all but a very few specialized salt-tolerant organisms.

From these and other examples, Lovelock concludes that "the climate and the chemical properties of the Earth now and throughout its history seem always to have been optimal for life," which seems hard to dispute, and that "for this to have happened by chance is as unlikely as to survive unscathed a drive blindfold through rush-hour traffic," which may also be true. Hence the need for Gaia (loosely from the Greek, and meaning Earth Mother), which Lovelock defines as "a complex entity involving the Earth's biosphere, atmosphere, oceans and soil; the totality constituting a feedback or cybernetic system which seeks an optimal physical and chemical environment for life on this planet," and for the Gaia Hypothesis, which "postulates that the physical and chemical condition of the surface of the Earth, of the atmosphere, and of the oceans has been and is actively made fit and comfortable by the presence of life itself."

It is not novel to suggest that life has profoundly changed the Earth, but it is novel and daring to suggest that it has done so in a seemingly deliberately adaptive way, in order to ensure its own continued existence. This sounds purposive, but Lovelock is careful to avoid the teleological trap; he assumes Gaia is the product of natural selection. Just as natural selection has mindlessly molded the behavior of individual bees so that they maintain their common hive at an optimal internal temperature, it has molded the behaviors of all the individual producers and consumers of carbon dioxide, oxygen, nitrogen and methane, and of all the organisms whose activities can influence global climate and oceanic salinity, so that these parameters will be maintained within ranges hospitable for life as a whole.

Gaia, as a cybernetic system, must have mechanisms for sensing when global physical and chemical parameters deviate from optimum, and mechanisms for initiating compensatory processes which will return those parameters to acceptable values (negative feedback). These admittedly will be difficult to identify, and Lovelock's imagination fails him in all but a few cases.

For instance, he gives examples of devices by which the biosphere might control temperature. If cooling is a problem, heat loss might be curtailed by reducing the Earth's albedo (or reflectance) by darkening its surface. Lovelock notes that algal mats, which may have covered large portions of the early Earth, are known today to be capable of darkening, and muses: "could these black mats, produced by life forms with a long ancestry, be living remnants of an ancient method of conserving warmth?" "Conversely, if over-heating were the cause of trouble, a marine biosphere would be able to control evaporation by producing a monomolecular layer with insulating properties to cover the surface of the waters. If evaporation from the warmer regions of the oceans were hindered by this means, it would prevent the excessive accumulation of water vapour in the atmosphere and the conditions of runaway heating by infrared absorption." Maybe so, but how does Gaia know if she is too cold or too hot, and how does she instruct the biosphere to behave accordingly? All Lovelock can say about this, after a long argument by analogy with body temperature control mechanisms in animals, is that "even though we may find evidence for a Gaian system of temperature regulation, the disentangling of its constitutive loops is unlikely to be easy if they are entwined as deeply as in the bodily regulation of temperature."

Atmospheric oxygen, the product of photosynthesis, can be kept in check by methane, the product of a diverse collection of ancient bacteria, the methanogens, which produce this gas in a variety of oxygen-free environments, principally anaerobic muds at the margins of seas, lakes and marshes. For Gaia to work as a cybernetic system,

methanogens must somehow respond to increasing atmospheric oxygen by more vigorous production of methane. Here Lovelock does a little better. Writing Andrew Watson and Lynn Margulis[2], he argues that increased oxygen leads to local overgrowths of oxygen-utilizing microbes in the waters overlying the muddy homes of the methanogens. The subsequent death and burial of these microbes enriches and extends the anaerobic (oxygen-free) environments in which methanogens thrive. This is a plausible scenario, and perhaps the most fully developed one Lovelock has to offer.

Lovelock's scheme for biological control of the saltiness of the sea seems much more strained. He notes that "excess salt accumulates in the form of evaporites in shallow bays, landlocked lagoons, and isolated arms of the sea, where the rate of evaporation is rapid and the inflow from the sea is one way." Such evaporation ponds will indeed decrease overall salinity. Lovelock then makes the "bold speculation that [these] lagoons formed as a consequence of life in the sea . . . Constructing vast barriers of the size needed to enclose thousands of square miles of sea in tropical regions may seem an engineering task well beyond human capabilities. Yet larger by far than any man-made structures are the coral reefs, and more significant in former times the [algal] stromatolite reefs. These are constructed on a Gaian scale, with city walls miles high and thousands of miles long, built by a cooperative of living organisms. Is it possible that the Great Barrier Reef, off the northeast coast of Australia, is the partly finished project for an evaporation lagoon?" I guess it *is* possible, but Lovelock is silent on the question of how Gaia knows her oceans are becoming too salty, how in response she instructs reef builders to construct such evaporation lagoons and why, in the last analyses, these intrepid creatures obey her instruction.

But it is not the difficulty of unravelling Gaian feedback loops that makes me doubt her existence. It is the impossibility of imagining *any* evolutionary mechanisms by which these loops could have arisen or now be maintained. In Hugh Lofting's book **Doctor Dolittle in the Moon**[3], John Dolittle marvels at the absence of Darwinian competition among the lunar flora and fauna. This, it turns out, reflected the dominance of "The Council," which was "made up of members from both the Animal and Vegetable Kingdoms. Its main purpose was to regulate life on the Moon in such a way that there should be no more warfare." Dolittle remarks to his aide, "our world that thinks itself so far advanced has not the wisdom, the foresight, Stubbins, which we have seen here. Fighting, fighting, fighting, always fighting! So it goes down there with us . . . The 'survival of the fittest'! . . . It is this thing here, this Council of Life – of life adjustment – that could have saved the day and brought happiness to all." Lovelock's Gaia is very much the terrestial equivalent of Lofting's lunar Council. But the Council was created by Otho Bludge, the first moon man and a refugee from Earth. Who created Gaia?

Lovelock is not explicit, but he implies that Gaia evolved as life evolved and if he is to be taken seriously at all, he must mean that she is the product of natural selection operating in the normal way but on a grand scale. And that must mean that organisms (or at least those with important geochemical impact) which behave in such a way as to contribute to the maintenance of Gaia have a greater probability of leaving offspring than those which do not.

Natural selection *always* has to operate in this way. That unit of selection which is more capable of long-term propagation than its competitors will (barring chance catastrophe) thrive at the expense of those competitors. There is currently controversy among evolutionary biologists – not about this nearly tautological axiom – but about what precisely is the unit of selection. The choices are the gene, the individual or the species (interbreeding population). Richard Dawkins, in **The Selfish Gene**[4], makes an especially compelling case for the gene as the unit of selection. In holding this view, he and other "sociobiologists" like E.O. Wilson differ from some earlier believers in "group selection" who maintained that traits which are detrimental to the individual but beneficial to the species will be maintained within a population by natural selection operating on the species as a whole. Sociobiologists like to interpret such apparently "altruistic" behavior in selfish terms: although such behavior may lead to individual death, it increases the probability of survival of genes for altruism the altruist shares with his relatives in the population. It is probably correct to say that most evolutionists now doubt that genetically-determined altruistic behavior without such an underlying selfish component can arise through natural selection. Sociobiologists have gotten into trouble only because they have tried to extend such reasoning to human behavior, where cultural determinants can operate independently of, and often in opposition to, genetic determinants. It is certainly correct to say that no serious student of evolution would suggest that natural selection could favor the development

2. Andrew Watson, James E. Lovelock and Lynn Margulis, **Biosystems**, Vol. 10, 293-298, 1978.

3. **Doctor Dolittle in the Moon**, by Hugh Lofting (J.P. Lippincott, 1928).

4. **The Selfish Gene**, by Richard Dawkins (Oxford University Press, 1976).

in one species of a behavior pattern which is beneficial to another with which it does not interbreed, if this behavior were either detrimental or of no selective value to the species itself. Mutually beneficial interspecies symbioses of course can arise: bees visit flowers because they get food that way, and flowers encourage bees to do so, because their pollen is spread in this way. In all such mutually beneficial symbioses, both partners must derive advantage, and each and every evolutionary step taken by one or the other partner in the development of a symbiosis, no matter how complex, must be immediately and individually beneficial to that partner.

Gaia is a symbiosis (or mutualism, in Wilson's terminology[5]) of global dimensions. The individual species comprising the partnership are immense in number and diverse in kind, and the time scale over which the actions of each member affect the welfare of all exceeds by many orders of magnitude the generation time of any. I cannot believe that natural selection could, without the intervention of something like Lofting's "Council," produce such a magnificent creature. For each member of the partnership to behave responsibly, there must be selective pressure against irresponsible behavior will not be felt for thousands or millions of years, during which time irresponsible mutants, which may well have a temporary selective advantage, would have replaced all responsible members of the species.

Lovelock himself provides a doomsday scenario in which an (artificially created) phosphate-sequestering photosynthetic microorganism grows explosively over all the waters of the Earth, disrupting all Gaian feedback loops and ultimately destroying all life on Earth, itself included. The scenario is not implausible, but Lovelock rejects it, saying "it was good to have no less an authority than John Postgate confirm that this brief essay in science fiction is indeed just a flight of fancy. In real life, there must be taboos written into the genetic coding, the universal language shared by every living cell. There must also be an intricate security system to ensure that exotic outlaw species do not evolve into rampantly criminal syndicates." I acknowledge the authority of Dr. Postgate, but what are these taboos? If evolutionary genetics and molecular biology have taught us anything, it is that the "purpose" of DNA (which embodies the genetic coding) is the making of more DNA, and in particular more DNA of its own kind. The means are as different as the different modes of reproduction exhibited by all living species, but the ends are always the same, and always justify the means. That is what evolution is all about, whether we like it or not. And what, specifically, is the "intricate security system" – it sounds like Lofting's "Council" – but who are its members and how do they function?

The rewards for good (Gaian) behavior are as remote as the penalties for bad behavior. It is difficult to accept that behaviors whose effects on atmospheric or oceanic composition or global temperature will not be felt for thousands of generations can be selected for, especially when the first beneficiaries of those effects may be organisms which are not themselves responsible for them. The construction of an evaporation lagoon for sequestration of sea salt may benefit the biosphere as a whole, in the very long run, but what in particular does it do for the organisms who construct it, especially in the short run? The global conflagration expected if oxygen levels exceed 25 percent would be disastrous to most higher forms of life. But it would produce a large amount of carbon dioxide and consume a lot of oxygen, and it is carbon dioxide which is the life-giving substrate for methanogens and it is oxygen which they must scrupulously avoid (because it is toxic to them). Would methanogens not in fact benefit, at least for thousands of years, from such a disaster? Organisms which produce methyl chloride may indeed help to regulate ozone in the stratosphere, but unless ozone varies quickly in response to their activities and ozone concentrations influence their own survival, there is no guarantee that methyl chloride will be produced in appropriate amounts.

I do not doubt that some of the feedback loops which Lovelock claims exist *do* exist, but I do doubt that they were created by natural selection, or that they are anything but accidental. Methane production may now balance oxygen production nicely, but it is *not* written into the genetic codes of either oxygen producers or methane producers that this should be so, and either could easily get out of hand. Accidental balances are fragile things, and their maintenance depends upon chance.

If the fitness of the terrestrial environment is accidental, then is Lovelock not right in saying that for life to have survived to reach the stage of self-awareness "is as unlikely as to survive unscathed a drive blindfold through rush-hour traffic"? I think he is right; the prolonged survival of life is an event of extraordinarily low probability. It is however an event which is a prerequisite for the existence of Jim Lovelock and thus for the formulation of the Gaia Hypothesis, and I think it is therefore logically fallacious to assume that any explanation other than chance is required. Can we not assume that there is an immense number of planets on which life independently arose and then

5. **Sociobiology: the new Synthesis**, by E.O. Wilson (The Belknap Press of Harvard University Press, 1975).

through some global catastrophe was extinguished before the evolution of self-awareness? And should we not expect that on those few planets on which intelligent beings arose, because such a catastrophe by chance did not occur, someone would seek to explain his own survival by the invocation of some protective device such as Gaia? Surely if a large enough number of blindfold drivers launched themselves into rush-hour traffic, one would survive, and surely he, unaware of the existence of his less fortunate colleagues, would suggest that something other than good luck was on his side.

Cosmologists seem to have grappled with a similar problem. B.J. Carr and M.S. Rees pointed out recently[6] that "the possibility of life as we know it evolving in the Universe depends on the values of a few basic physical constants, and is in some respects remarkably sensitive to their numerical values." They do not assume, however, that life has manipulated these constants (which *a priori* could have many other values) for its own ends, because there is a simpler explanation. Only the known values are *potentially observable*, because other values would not have permitted the evolutionary development of observers. Similarly, only a world which behaved *as if* Gaia did exist is observable, because only such a world can produce observers.

Does it matter if Lovelock is wrong, and the apparent stability of the biosphere reflects not the operation of a global cybernetic system created by natural selection to maintain conditions which are optimal for life, but sheer good luck? Yes it does, because Gaia, if she exists, has built-in corrective mechanisms and buffering systems which will protect the biosphere against many potential threats to its survival. An accidental system, although it may have some accidentally-developed buffering capacity, is inherently fragile and cannot evolve in the adaptive way Gaia could (if she were real) in response to new threats.

The last two chapters of Lovelock's book are

CATALOG OF THE UNIVERSE (CROWN, 1979)

Thunderstorms over the Amazon tropical rain forest seen from Apollo 9. The current jeopardy of the rain forest may jeopardize Gaia.

6. B.J. Carr and M.J. Rees, Nature, Vol. 278, 605-612, 1979.

James Lovelock Responds

A Bishop recently asked me "Which came first, Life, or Gaia?" Dr. Doolittle's critique assumes that Life did and that Gaia as a development of Life cannot exist — for natural selection as he interprets it would not permit it.

I prefer to regard Gaia at this stage of knowledge as a manifestation of tendency in this Universe for complex systems to be stable and survive. Interestingly, R. Dawkins in his book "The Selfish Gene" also raises the possibility that Natural Selection among systems predated Life and that Darwin's great work was a subset of a deeper generality. To illustrate this point consider a hurricane. It is not living but it is an association of vortices which is much more stable and has more style than any mere low on the weather map. We recognise hurricanes as proto-life and give them names. It is even recognised among mathematicians that systems of differential equations when they interact tend to a kind of homeostasis.

Doolittle may be right that the selfish genes would never wish to form a trades union like Gaia. But what he and other evolutionists seem to ignore is the fact that the presence and the products of life inevitably and inexorably modify the environment. The options then open to life as a whole are constrained by its past activities. It is not a big step for loops to then begin to close and for life to become included within a larger albeit tenuous entity. It may be difficult from deep within the dogma of molecular biology to think of the cybernetic consequences of evolution but the loop is not open, it is closed, and Gaia may not after all be inconsistent with natural selection.

The second part of his critique concerns environmentalism. Doolittle attributes to me the belief

devoted to interactions between Gaia and her newest and potentially least responsible partner, man. Lovelock writes "it is now generally accepted that man's industrial activities are fouling the nest and pose a threat to the total life of the planet which grows more ominous every year. Here, however, I [Lovelock] part company with conventional thought. It may be that the white-hot rash of our technology will in the end prove destructive and painful for our own species, but the evidence for accepting that industrial activities either at their present level or in the immediate future may endanger the life of Gaia as a whole, is very weak indeed."

Lovelock *does* worry about the possibility of matricidal destruction of Gaia, but he worries about it in a different way. For instance, he considers the sloppy use of spray cans to be a relatively harmless perversion, because Gaia has already established cybernetic systems for maintaining atmospheric ozone at levels suitable for the survival of the biosphere. It is not the poisons which man produces which threaten Gaia; we can only kill her by displacing vital members of the partnership whose metabolic activities are essential components of the many feedback loops. And we can do this by perturbing the environments in which these essential partners live, in particular the "tropics and the seas close to the continental shores. It is in these regions, where few do watch, that harmful practices may be pursued to the point of no-return before their dangers are recognized . . ." Lovelock is right in pointing out these danger points, because even if natural balances are only accidental, we perturb them at our peril. But, *unless Gaia really does exist*, he is wrong in suggesting that we need not be equally concerned about spray cans, about the increasing production of carbon dioxide which results from the use of any organic matter as fuel, about acid rain, or about any of the other threats to global survival around which properly concerned environmentalists construct their various doomsday scenarios. Herein lies the danger in accepting the existence of Gaia. □

that Gaia by taking care of everything gives industry a green light to pollute at will. This is not what I said. I think that there is only one pollution, namely people. When there are too many of them almost anything, even eventually breathing, can be a pollution. Ever been in a London Underground train at rush hour, which breaks down in a tunnel? Try it and see what I mean.

I am not unconcerned about CO_2 or acid rain or even the ozone war. I just think that the environmentalists have their priorities misplaced. They agonize over a still unproven hypothesis, that the current production of fluorocarbons might slightly deplete ozone, when the tropical forests are being ripped off at a rate which could eliminate them in two decades. This to me is truly straining at the gnat while swallowing the camel.

Furthermore the ozone scare looks to be ethnocentric. Apparently it is OK for Indians to suffer rickets from lack of UV but it would be terrible if a few whites suffered cosmetic damage from curable skin cancer. In fact ozone is still increasing, so it is the Indians who are losing the ozone war.

Although I disagree with Dr. Doolittle's criticism of Gaia on environmentalist arguments, I am very grateful to him for rousing my interest in molecular biology. Perhaps he may find cybernetics equally rewarding. □

Lynn Margulis Responds

(Microbiologist at Boston University who collaborated with Lovelock on Gaia Hypothesis. A brief biography of her career appeared in the Spring 1980 CQ.)

Gaia lives, has blurred boundaries

Doolittle's review of Jim Lovelock's book **Gaia** *is marvelous for its brevity, accuracy, and clarity. It is the single best statement about what is valuable in that book that I have seen. However, it suffers from several grave errors, the first in the second sentence.*

Single factor hypotheses of the evolutionary process went out with the 19th century. That natural selection alone is the force "responsible for the existence and characteristics of the biosphere" is patently false. There are at least three components to the evolutionary process, each itself multifaceted: faithful replication (high heritability); inherited variation (of many sorts — point mutations, duplications, chromosomal alterations, karyotypic fissions, hereditary endosymbioses); and natural selection. Without the first two, natural selection has nothing upon which to act. Taken together the evolutionary process does explain the emergence of Gaia as a control system, although admittedly many detailed mechanisms — indeed most — remain to be explained.

Doolittle admits that the difficulty of unraveling Gaia's feedback loops does not make him doubt her existence. Thus everyone is in agreement that