



The **Gaia hypothesis** is an ecological hypothesis proposing that the biosphere and the physical components of the Earth (atmosphere, cryosphere, hydrosphere and lithosphere) are closely integrated to form a complex interacting system that maintains the climatic and biogeochemical conditions on Earth in a preferred homeostasis. Originally proposed by James Lovelock as the earth feedback hypothesis, ^[1] it was named the Gaia Hypothesis after the Greek supreme goddess of Earth. ^[2] The hypothesis is frequently described as viewing the Earth as a single organism. Lovelock and other supporters of the idea now call it

Gaia theory,

regarding it as a scientific theory and not mere hypothesis, since they believe it has passed predictive tests.

^[3]

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// **History**

The Gaia hypothesis was first scientifically formulated in the 1960s by the independent research scientist James Lovelock, as a consequence of his work for NASA on methods of detecting life on Mars. ^[4] ^[5] He initially published the *Gaia Hypothesis* in journal articles in the early 1970s ^[6] ^[7]

followed by a popularizing 1979 book
Gaia: A new look at life on Earth

The theory was initially, according to Lovelock, a way to explain the fact that combinations of chemicals including oxygen and methane persist in stable concentrations in the atmosphere of the Earth. Lovelock suggested using such combinations detected in other planets' atmospheres would be a relatively reliable and cheap way to detect life, which many biologists opposed at the time and since. Later other relationships such as the fact that sea creatures produce sulfur and iodine in approximately the quantities required by land creatures emerged and helped bolster the theory. Rather than invent many different theories to describe each such equilibrium, Lovelock dealt with them holistically, naming this self-regulating living system after the Greek goddess Gaia, using a suggestion from the novelist William Golding, who was living in the same

village as Lovelock at the time (Bowerchalke, Wiltshire, UK). The Gaia Hypothesis has since been supported by a number of scientific experiments [\[8\]](#) and provided a number of useful predictions, [\[9\]](#) and hence is properly referred to as the Gaia Theory.

Since 1971, the noted microbiologist Dr. Lynn Margulis has been Lovelock's most important collaborator in developing Gaian concepts. [\[10\]](#)

Until 1975 the hypothesis was almost totally ignored. An article in the New Scientist of February 15, 1975, and a popular book length version of the theory, published in 1979 as *The Quest for Gaia*, began to attract scientific and critical attention to the hypothesis. The theory was then attacked by many mainstream biologists. Championed by certain environmentalists and climate scientists, it was vociferously rejected by many others, both within scientific circles and outside them.

Lovelock's initial hypothesis

James Lovelock defined Gaia 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.

His initial hypothesis was that the biomass modifies the conditions on the planet to make conditions on the planet more hospitable – the Gaia Hypothesis properly defined this "hospitality" as a full homeostasis. Lovelock's initial hypothesis, accused of being teleological by his critics, was that the atmosphere is kept in homeostasis by and for the biosphere.

Lovelock suggested that life on Earth provides a cybernetic, homeostatic feedback system operated automatically and unconsciously by the biota, leading to broad stabilization of global temperature and chemical composition.

With his initial hypothesis, Lovelock claimed the existence of a global control system of surface temperature, atmosphere composition and ocean salinity. His arguments were:

- The global surface temperature of the Earth has remained constant, despite an increase in the energy provided by the Sun.
- Atmospheric composition remains constant, even though it should be unstable.
- Ocean salinity is constant.

Since life started on Earth, the energy provided by the Sun has increased by 25% to 30%; [\[11\]](#) however the surface temperature of the planet has remained remarkably constant when measured on a global scale. Furthermore, he argued, the atmospheric composition of the Earth is constant.

[\[12\]](#)

The Earth's atmosphere currently consists of 79% nitrogen, 20.7% oxygen and 0.03% carbon dioxide. Oxygen is the second most reactive element after fluorine, and should combine with gases and minerals of the Earth's atmosphere and crust. Traces of methane (at an amount of 100,000 tonnes produced per annum)

[\[13\]](#)

should not exist, as methane is combustible in an oxygen atmosphere. This composition should be unstable, and its stability can only have been maintained with removal or production by living organisms.

Ocean salinity has been constant at about 3.4% for a very long time. [\[14\]](#) Salinity stability is important as most cells require a rather constant salinity and do not generally tolerate values above 5%. Ocean salinity constancy was a long-standing mystery, because river salts should have raised the ocean salinity much higher than observed. Recently it was suggested

[\[15\]](#)

that salinity may also be strongly influenced by seawater circulation through hot basaltic rocks, and emerging as hot water vents on ocean spreading ridges. However, the composition of sea water is far from equilibrium, and it is difficult to explain this fact without the influence of organic processes.

The only significant natural source of atmospheric carbon dioxide (CO₂) is volcanic activity, while the only significant removal is through the precipitation of carbonate rocks.

[\[16\]](#)

In water, CO

2

is dissolved as a "carbonic acid," which may be combined with dissolved calcium to form solid calcium carbonate (limestone). Both precipitation and solution are influenced by the bacteria and plant roots in soils, where they improve gaseous circulation, or in coral reefs, where calcium carbonate is deposited as a solid on the sea floor. Calcium carbonate can also be washed from continents to the sea where it is used by living organisms to manufacture carbonaceous tests and shells. Once dead, the living organisms' shells fall to the bottom of the oceans where they

generate deposits of chalk and limestone. Part of the organisms with carbonaceous shells are the coccolithophores (algae), which also have a role in the formation of clouds. When they die, they release dimethyl sulfide gas (DMS), (CH

³
)
²
S, which is converted by atmospheric processes to sulfate particles on which water vapor condenses to make clouds.

[\[17\]](#)

Lovelock sees this as one of the complex processes that maintain conditions suitable for life. The volcanoes produce CO₂ in the atmosphere, CO₂ participates in rock weathering as carbonic acid, itself accelerated by temperature and soil life, the dissolved CO

²
is then used by the algae and released on the ocean floor. CO

²
excess can be compensated by an increase of coccolithophoride life, increasing the amount of CO

²
locked in the ocean floor. Coccolithophorides increase the cloud cover, hence control the surface temperature, help cool the whole planet and favor precipitations which are necessary for terrestrial plants. For Lovelock and other Gaia scientists like Stephan Harding, coccolithophorides are one stage in a regulatory feedback loop. Lately the atmospheric CO

²
concentration has increased and there is some evidence that concentrations of ocean algal blooms are also increasing.

[\[18\]](#)

Controversial concepts

Lovelock, especially in his older texts, used language that has later caused fiery debate. For instance, many of his biological critics such as Stephen Jay Gould and Richard Dawkins attacked his statement in the first paragraph of his first Gaia book (1979), that "the quest for Gaia is an attempt to find the largest living creature on Earth." [\[19\]](#)

Lynn Margulis, the coauthor of Gaia hypotheses, is more careful to avoid controversial figures of speech than is Lovelock. In 1979 she wrote, in particular, that only homeorhetic and not homeostatic balances are involved: that is, the composition of Earth's atmosphere, hydrosphere, and lithosphere are regulated around "set points" as in homeostasis, but those set points change with time. Also she wrote that there is no special tendency of biospheres to preserve their current inhabitants, and certainly not to make them comfortable. Accordingly, the

Earth is a kind of community of trust which can exist at many discrete levels of integration. This is true for all multicellular organisms which do not live or die all at once: not all cells in the body die instantaneously, nor are homeostatic "set points" constant through the life of an organism.

Critical analysis

This theory is based on the idea that the biomass self-regulates the conditions on the planet to make its physical environment (in particular temperature and chemistry of the atmosphere) on the planet more hospitable to the species which constitute its "life". The Gaia Hypothesis properly defined this "hospitality" as a full homeostasis. A model that is often used to illustrate the original Gaia Hypothesis is the so-called Daisyworld simulation.

Whether this sort of system is present on Earth is still open to debate. Some relatively simple homeostatic mechanisms are generally accepted. For example, when atmospheric carbon dioxide levels rise, the biomass of photosynthetic organisms increases and thus removes more carbon dioxide from the atmosphere, but the extent to which these mechanisms stabilize and modify the Earth's overall climate are not yet known. Less clear is the reason why such traits should evolve in a system in order to produce such effects. Lovelock accepts a process of systemic Darwinian evolution for such mechanisms, creatures that evolve that improve their environment for their survival will do better than those which damage their environment. But many scientists do not believe such mechanisms exist. [\[20\]](#)

Criticism

After initially being largely ignored by most scientists, (from 1969 until 1977), thereafter for a period, the initial Gaia hypothesis was ridiculed by a number of scientists, like Ford Doolittle, Dawkins and Gould. Lovelock has said that by naming his theory after a Greek goddess, championed by many non scientists [\[1\]](#), the Gaia hypothesis was derided as some kind of neo-Pagan New Age religion. Many scientists in particular also criticised the approach taken in his popular book "Gaia, a New look at Life on Earth" for being teleological; a belief that all things have a predetermined purpose. Lovelock seems to have accepted this criticism of some of his statements, and has worked hard to remove the taint of teleological thinking from his theories, stating "Nowhere in our writings do we express the idea that planetary self-regulation is purposeful, or involves foresight or planning by the biota." – (Lovelock, J. E. 1990).

In 1981, W. Ford Doolittle, in the *CoEvolution Quarterly* article "Is Nature Motherly" argued that there was nothing in the genome of individual organisms which could provide the feedback mechanisms Gaia theory proposed, and that therefore the Gaia hypothesis was an unscientific theory of a maternal type without any explanatory mechanism. In Richard Dawkins' 1982 book,

The Extended Phenotype

, he argued that organisms could not act in concert as this would require foresight and planning from them. Like Doolittle he rejected the possibility that feedback loops could stabilize the system. Dawkins claimed "there was no way for evolution by natural selection to lead to altruism on a Global scale".

Stephen Jay Gould criticised Gaia as merely a metaphorical description of Earth processes [\[21\]](#) . He wanted to know the actual mechanisms by which self-regulating homeostasis was regulated. Lovelock argues that no one mechanism is responsible, that the connections between the various known mechanisms may never be known, that this is accepted in other fields of biology and ecology as a matter of course, and that specific hostility is reserved for his own theory for political reasons.

Aside from clarifying his language and understanding of what is meant by a life form, Lovelock himself ascribes most of the criticism to a lack of understanding of non-linear mathematics by his critics, and a linearizing form of greedy reductionism in which all events have to be immediately ascribed to specific causes before the fact. He notes also that his theory suggests experiments in many different fields, but few of them in biology which most of his critics are trained in. "I'm a general practitioner in a world where there's nothing but specialists... science in the last two centuries has tended to be ever-dividing" and often rivalrous, especially for funding which Lovelock describes as overly abundant and overly focused on institutions rather than original thought. He points out that Richard Feynman not only shared this opinion (coining the term cargo cult science) but also accepted a lack of general cause and effect explanation as an inevitable phase in a theory's development, and believed that some self-regulating phenomena may not be explainable at all mathematically.

Theory

One of the criteria of the empirical definition of life is its ability to replicate and pass on their genetic information to succeeding generations. Consequently, an argument against the idea that Gaia is a "living" organism is the fact that the planet is unable to reproduce.

Lovelock, however, defines life as a self-preserving, self-similar system of feedback loops like Humberto Maturana's autopoiesis; as a self-similar system, life could be a cell as well as an organ embedded into a larger organism as well as an individual in a larger inter-dependent social context. The biggest context of interacting inter-dependent living entities is the Earth. The problematic empirical definition is getting "fuzzy on the edges": Why are highly specialized bacteria like *E. coli* that are unable to thrive outside their habitat considered "life", while mitochondria, which have evolved independently from the rest of the cell, are not?

Maturana and Lovelock changed this with the autopoiesis deductive definition which to them explains the phenomenon of life better; some aspects of the empirical definition, however, no longer apply. Reproduction becomes optional: bee swarms reproduce, while the biosphere has no need to. Lovelock himself states in the original Gaia book that even that is not true; given the possibilities, the biosphere may multiply in the future by colonizing other planets, as humankind may be the primer by which Gaia will reproduce. Humanity's exploration of space, its interest in colonizing and even terraforming other planets, lends some plausibility to the idea that Gaia might in effect be able to reproduce.

The astronomer Carl Sagan also remarked that from a cosmic viewpoint, the space probes since 1959 have the character of a planet preparing to go to seed [\[22\]](#). This might warrant interpretation as a rhetorical point, however, as it equivocates two differing meanings of "reproduction" otherwise.

Daisyworld simulations

Lovelock responded to criticisms by developing the mathematical model Daisyworld with Andrew Watson to demonstrate that feedback mechanisms could evolve from the actions or activities of self-interested organisms, rather than through classic group selection mechanisms. [\[23\]](#)

Daisyworld examines the energy budget of a planet populated by two different types of plants, black daisies and white daisies. The colour of the daisies influences the albedo of the planet such that black daisies absorb light and warm the planet, while white daisies reflect light and cool the planet. Competition between the daisies (based on temperature-effects on growth rates) leads to a balance of populations that tends to favour a planetary temperature close to that which is optimum for the daisy growth. Lovelock and Watson demonstrated the stability of Daisyworld by forcing the sun that it orbits to evolve along the main sequence, taking it from low to high solar constant. This perturbation of Daisyworld's receipt of solar radiation caused the balance of daisies to gradually shift from black to white but the planetary temperature was always regulated back to this optimum (except at the extreme ends of solar evolution). This situation is very different from the corresponding abiotic world, where temperature is unregulated and rises linearly with solar output. Later versions of Daisyworld introduced a range of grey daisies and populations of grazers and predators, and found that these further increased the stability of the homeostasis. More recently other research, modelling the real biochemical cycles of Earth, and using various "guilds" of life (eg. photosynthesisers, decomposers, herbivores and primary and secondary carnivores) has also been shown to produce Daisyworld-like regulation and stability, which helps to explain planetary biological diversity.

This enables nutrient recycling within a regulatory framework derived by natural selection amongst species, where one being's harmful waste becomes low energy food for members of another guild. This research on the Redfield ratio of Nitrogen to Phosphorus shows that local biotic processes can regulate global systems (See Keith Downing & Peter Zvirinsky, *The Stimulated Evolution of Biochemical Guilds: Reconciling Gaia Theory with Natural Selection*).

First Gaia conference

In 1988, to draw attention to the Gaia hypothesis, the climatologist Stephen Schneider organised a conference of the American Geophysical Union's first Chapman Conference on Gaia, held at San Diego in 1989, solely to discuss Gaia.

At the conference James Kirchner criticised the Gaia hypothesis for its imprecision. He claimed that Lovelock and Margulis had not presented one Gaia hypothesis, but four -

- CoEvolutionary Gaia — that life and the environment had evolved in a coupled way. Kirchner claimed that this was already accepted scientifically and was not new.
- Homeostatic Gaia — that life maintained the stability of the natural environment, and that this stability enabled life to continue to exist.
- Geophysical Gaia — that the Gaia theory generated interest in geophysical cycles and therefore led to interesting new research in terrestrial geophysical dynamics.
- Optimising Gaia — that Gaia shaped the planet in a way that made it an optimal environment for life as a whole. Kirchner claimed that this was not testable and therefore was not scientific.

Of Homeostatic Gaia, Kirchner recognised two alternatives. "Weak Gaia" asserted that life tends to make the environment stable for the flourishing of all life. "Strong Gaia" according to Kirchner, asserted that life tends to make the environment stable, *in order to enable* the flourishing of all life. Strong Gaia, Kirchner claimed, was untestable and therefore not scientific.

Referring to the Daisyworld Simulations, Kirchner responded that these results were predictable because of the intention of the programmers — Lovelock and Watson, who selected examples which would produce the responses they desired.

Lawrence Joseph in his book "Gaia: the birth of an idea" argued that Kirchner's attack was principally against Lovelock's integrity as a scientist. Lovelock did not attack Kirchner's views for ten years, until his autobiography "Homage to Gaia", where he calls Kirchner's position *sophistry*.

Lovelock and other Gaia-supporting scientists, however, did attempt to disprove the claim that the theory is not scientific because it is impossible to test it by controlled experiment. For example, against the charge that Gaia was teleological Lovelock and Andrew Watson offered the Daisyworld model (and its modifications, above) as evidence against most of these criticisms.

Lovelock was careful to present a version of the Gaia Hypothesis which had no claim that Gaia intentionally or consciously maintained the complex balance in her environment that life needed to survive. It would appear that the claim that Gaia acts "intentionally" was a metaphoric statement in his popular initial book and was not meant to be taken literally. This new statement of the Gaia hypothesis was more acceptable to the scientific community.

The accusations of teleologism were largely dropped after this conference.

Range of views

Some have found James Kirchner's suggested spectrum, proposed at the First Gaia Chapman Conference, useful in suggesting that the original Gaia hypothesis could be split into a spectrum of hypotheses, ranging from the undeniable (Weak Gaia) to the radical (Strong Gaia).

Weak Gaia

At one end of this spectrum is the undeniable statement that the organisms on the Earth have altered its composition. A stronger position is that the Earth's biosphere effectively acts as if it is a self-organizing system, which works in such a way as to keep its systems in some kind of "meta-equilibrium" that is broadly conducive to life. The history of evolution, ecology and climate show that the exact characteristics of this equilibrium intermittently have undergone rapid changes, which are believed to have caused extinctions and felled civilizations (see climate change).

Weak Gaian hypotheses suggest that Gaia is co-evolutive. Co-evolution in this context has

been thus defined: "Biota influence their abiotic environment, and that environment in turn influences the biota by Darwinian process." Lovelock (1995) gave evidence of this in his second book, showing the evolution from the world of the early thermo-acido-philic and methanogenic bacteria towards the oxygen enriched atmosphere today that supports more complex life.

The weakest form of the theory has been called "influential Gaia". It states that biota minimally influence certain aspects of the abiotic world, e.g. temperature and atmosphere.

The weak versions are more acceptable from an orthodox science perspective, as they assume non-homeostasis. They state the evolution of life and its environment may affect each other. An example is how the activity of photosynthetic bacteria during Precambrian times have completely modified the Earth atmosphere to turn it aerobic, and as such supporting evolution of life (in particular eukaryotic life). However, these theories do not claim the atmosphere modification has been done in coordination and through homeostasis. Also such critical theories have yet to explain how conditions on Earth have not been changed by the kinds of run-away positive feedbacks that have affected Mars and Venus.

Biologists and earth scientists usually view the factors that stabilize the characteristics of a period as an undirected emergent property or entelechy of the system; as each individual species pursues its own self-interest, for example, their combined actions tend to have counterbalancing effects on environmental change. Opponents of this view sometimes reference examples of lives' actions that have resulted in dramatic change rather than stable equilibrium, such as the conversion of the Earth's atmosphere from a reducing environment to an oxygen-rich one. However, proponents argue these atmospheric changes improved the environment's suitability for life.

Some go a step further and hypothesize that all lifeforms are part of one single living planetary being called *Gaia*. In this view, the atmosphere, the seas and the terrestrial crust would be results of interventions carried out by Gaia through the coevolving diversity of living organisms. While it is arguable that the Earth as a unit does not match the generally accepted biological criteria for life itself (*Gaia* has not yet reproduced, for instance; it still might *spread* to other planets through human space colonization and terraforming), many scientists would be comfortable characterizing the earth as a single "system".

Strong Gaia

A version called "Optimizing Gaia" asserts that biota manipulate their physical environment for the purpose of creating biologically favorable, or even optimal, conditions for themselves. "The Earth's atmosphere is more than merely anomalous; it appears to be a contrivance specifically constituted for a set of purposes" ^[7]. Further, "... it is unlikely that chance alone accounts for the fact that temperature, pH and the presence of compounds of nutrient elements have been, for immense periods, just those optimal for surface life. Rather, ... energy is expended by the biota to actively maintain these optima" ^[7].

Another strong hypothesis is the one called "Omega Gaia" ^[24]. Teilhard de Chardin claimed that the Earth is evolving through stages of cosmogenesis, affecting the geosphere, biogenesis of the biosphere, and noogenesis of the noosphere, culminating in the *Omega Point*

. Another form of the strong Gaia hypothesis is proposed by Guy Murchie who extends the quality of a holistic lifeform to galaxies. "After all, we are made of star dust. Life is inherent in nature." Murchie describes geologic phenomena such as sand dunes, glaciers, fires, etc. as living organisms, as well as the life of metals and crystals. "The question is not whether there is life outside our planet, but whether it is possible to have "nonlife".

There are speculative versions of the Gaia hypothesis, including versions in which it is held that the Earth is conscious or part of some universe-wide evolution such as expressed in the Selfish Biocosm hypothesis strain of a larger speculative Gaia philosophy. These extreme forms of the Gaia hypothesis, that the entire Earth is a single unified organism that is *consciously* manipulating the climate in order to make conditions more conducive to life, are metaphysical or mystical views for which no evidence exists, and which cannot be tested scientifically. Another strain which also goes further than science presently justifies, is the Gaia Movement, a collection of different organisations operating in different countries, but all sharing a concern for how humans might live more sustainably within the "living system".

Recent developments

Gaia Theory has developed considerably and in recent years both Lovelock's and Margulis's understanding of Gaia have gained some increased support as a potentially viable, testable scientific hypothesis or theory. ^[10] ^[25]. Margulis dedicated the last of eight chapters in her book, *The Symbiotic Planet*, to Gaia. She resented the widespread personification of Gaia and stressed that Gaia is "not an organism", but "an emergent property of interaction among organisms". She defined Gaia "the series of interacting ecosystems that compose a single huge ecosystem at the Earth's surface. Period." Yet still she argues, "the surface of the planet behaves as a physiological system in certain limited ways". Margulis seems to agree with Lovelock in that, in what comes to these physiological processes, the Earth's surface is "best regarded as alive". The book's most memorable "slogan" was

actually quipped by a student of Margulis': "Gaia is just symbiosis as seen from space". This neatly connects Gaia theory to Margulis' own theory of endosymbiosis.

Second Gaia conference

By the time of the 2nd Chapman Conference on the Gaia Hypothesis, held at Valencia, Spain, on 23 June 2000, the situation had developed significantly in accordance with the developing science of Bio-geophysiology. Rather than a discussion of the Gaian teleological views, or "types" of Gaia Theory, the focus was upon the specific mechanisms by which basic short term homeostasis was maintained within a framework of significant evolutionary long term structural change.

The major questions were:

1. "How has the global biogeochemical/climate system called Gaia changed in time? What is its history? Can Gaia maintain stability of the system at one time scale but still undergo vectorial change at longer time scales? How can the geologic record be used to examine these questions?"

2. "What is the structure of Gaia? Are the feedbacks sufficiently strong to influence the evolution of climate? Are there parts of the system determined pragmatically by whatever disciplinary study is being undertaken at any given time or are there a set of parts that should be taken as most true for understanding Gaia as containing evolving organisms over time? What are the feedbacks among these different parts of the Gaian system, and what does the near closure of matter mean for the structure of Gaia as a global ecosystem and for the productivity of life?"

3. "How do models of Gaian processes and phenomena relate to reality and how do they help address and understand Gaia? How do results from Daisyworld transfer to the real world? What are the main candidates for "daisies"? Does it matter for Gaia theory whether we find daisies or not? How should we be searching for daisies, and should we intensify the search? How can Gaian mechanisms be investigated using process models or global models of the climate system which include the biota and allow for chemical cycling?"

In 1997, Tyler Volk argued that a Gaian system is almost inevitably produced as a result of an evolution towards far-from-equilibrium homeostatic states that maximise entropy production, and Kleidon (2004) agreed stating: "...homeostatic behavior can emerge from a state of MEP associated with the planetary albedo"; "...the resulting behavior of a biotic Earth at a state of MEP may well lead to near-homeostatic behavior of the Earth system on long time scales, as stated by the Gaia hypothesis." Staley (2002) has similarly proposed "...an alternative form of Gaia theory based on more traditional Darwinian principles... In [this] new approach, environmental regulation is a consequence of population dynamics, not Darwinian selection.

The role of selection is to favor organisms that are best adapted to prevailing environmental conditions. However, the environment is not a static backdrop for evolution, but is heavily influenced by the presence of living organisms. The resulting co-evolving dynamical process eventually leads to the convergence of equilibrium and optimal conditions."

Third Gaia conference

A third international conference on the Gaia Theory, sponsored by the Northern Virginia Regional Park Authority and others, was held in October 2006 at the Arlington, VA campus of George Mason University. Lynn Margulis, Distinguished University Professor in the Department of Geosciences, University of Massachusetts-Amherst, and long-time advocate of the Gaia Theory, was a keynote speaker. Among many other speakers: Tyler Volk, Co-director of the Program in Earth and Environmental Science at New York University; Dr. Donald Aitken, Principal of Donald Aitken Associates; Dr. Thomas Lovejoy, President of the Heinz Center for Science, Economics and the Environment; Robert Correll, Senior Fellow, Atmospheric Policy Program, American Meteorological Society and noted environmental ethicist, J. Baird Callicott. James Lovelock, the theory's progenitor, prepared a video specifically for the event.

This conference approached Gaia Theory as both science and metaphor as a means of understanding how we might begin addressing 21st century issues such as climate change and ongoing environmental destruction.

Gaia hypothesis in ecology

After much criticism, a modified Gaia hypothesis is now considered within ecological science basically consistent with the planet Earth being the ultimate object of ecological study. Ecologists generally consider the biosphere as an ecosystem and the Gaia hypothesis, though a simplification of that original proposed, to be consistent with a modern vision of global ecology, relaying the concepts of biosphere and biodiversity. The Gaia hypothesis has been called geophysiology or Earth System Science, which takes into account the interactions between biota, the oceans, the geosphere, and the atmosphere. To promote research and discussion in these fields an organisation, "Gaia Society for Research and Education in Earth System Science" was started.

An example of the change in acceptability of Gaia theories is the Amsterdam declaration of the scientific communities of four international global change research programmes — the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP) and the international biodiversity programme DIVERSITAS — recognise that, in

addition to the threat of significant climate change, there is growing concern over the ever-increasing human modification of other aspects of the global environment and the consequent implications for human well-being.

They state

"Research carried out over the past decade under the auspices of the four programmes to address these concerns has shown that:

1. The Earth System behaves as a single, self-regulating system with physical, chemical, biological, and human components. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability. The understanding of the natural dynamics of the Earth System has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.

2. Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change. Anthropogenic changes to Earth's land surface, oceans, coasts and atmosphere and to biological diversity, the water cycle and biogeochemical cycles are clearly identifiable beyond natural variability. They are equal to some of the great forces of nature in their extent and impact. Many are accelerating. Global change is real and is happening now.

3. Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth System in complex ways. These effects interact with each other and with local- and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict.

4. Earth System dynamics are characterised by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants. The Earth System has operated in different states over the last half million years, with abrupt transitions (a decade or less) sometimes occurring between them. Human activities have the potential to switch the Earth System to alternative modes of operation that may prove irreversible and less hospitable to humans and other life. The probability of a human-driven abrupt change in Earth's environment has yet to be quantified but is not negligible.

5. In terms of some key environmental parameters, the Earth System has moved well outside the range of the natural variability exhibited over the last half million years at least. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented. The Earth is currently operating in a no-analogue state."

Sir Crispin Tickell in the 46th Annual Bennett Lecture for the 50th Anniversary of Geology at the University of Leicester in his recent talk "Earth Systems Science: Are We Pushing Gaia Too Hard?" stated "as a theory, Gaia is now winning." [\[26\]](#)

He continued "The same goes for the earth systems science which is now the concern of the Geological Society of London (with which the Gaia Society recently merged). Whatever the label, earth systems science, or Gaia, has now become a major subject of inquiry and research, and no longer has to justify itself."

These findings would seem to be fully in accord with the Gaia theory. Despite this endorsement, the late W. D. Hamilton, one of the founders of modern Darwinism, whilst conceding the empirical basis of the planetary homeostatic processes on which Gaia is based, states that it is a theory still awaiting its Copernicus. The homeostatic nature of the global system has been recognized as a consequence of the 2nd law of thermodynamics. [\[27\]](#) In their comprehensive book on the thermodynamics of life, Eric D. Schneider and Dorion Sagan argue that Gaia belongs to a class of complex thermodynamic systems, not just living ones, that are naturally purposeful; and that life optimizes rather than maximizes entropy production.

[\[28\]](#)

The Revenge of Gaia

In James Lovelock's 2006 book, *The Revenge of Gaia*, he argues that the lack of respect humans have had for Gaia, through the damage done to rainforests and the reduction in planetary biodiversity, is testing Gaia's capacity to minimize the effects of the addition of greenhouse gases in the atmosphere. This eliminates the planet's negative feedbacks and increases the likelihood of homeostatic positive feedback potential associated with runaway global warming. Similarly the warming of the oceans is extending the oceanic thermocline layer of tropical oceans into the Arctic and Antarctic waters, preventing the rise of oceanic nutrients into the surface waters and eliminating the algal blooms of phytoplankton on which oceanic foodchains depend. As phytoplankton and forests are the main ways in which Gaia draws down greenhouse gases, particularly carbon dioxide, taking it out of the atmosphere, the elimination of this environmental buffering will see, according to Lovelock, most of the earth becoming uninhabitable for humans and other life-forms by the middle of this century, with a massive extension of tropical deserts.

Given these conditions, Lovelock expects human civilization will be hard pressed to survive. He expects the change to be similar to the Paleocene-Eocene Thermal Maximum when atmospheric concentration of CO₂ was 450 ppm. At that point the Arctic Ocean was 23 °C and

had crocodiles in it, with the rest of the world mostly scrub and desert. He says of sustainable development and renewable energy that it came "200 years too late" and that more effort should go into adaptation, including more use of fission. He likens the Kyoto Protocol to the Munich conferences that failed to prevent World War II, including the likelihood that the disaster will cause people to come together in common cause. "We have been through no less than seven of these events as humans...comparable in extent to the change" likely to be wrought by global warming.

He claims that Gaia's self-regulation will likely prevent any extraordinary runaway effects that wipe out life itself, but that humans will survive and be "culled and, I hope, refined."

According to James Lovelock, by 2040, the world population of more than six billion will have been culled by floods, drought and famine. Indeed *[t]he people of Southern Europe, as well as South-East Asia, will be fighting their way into countries such as Canada, Australia and Britain*

[\[29\]](#)

"By 2040, parts of the Sahara desert will have moved into middle Europe. We are talking about Paris - as far north as Berlin. In Britain we will escape because of our oceanic position."

[\[29\]](#)

"If you take the Intergovernmental Panel on Climate Change predictions, then by 2040 every summer in Europe will be as hot as it was in 2003 - between 110F and 120F. It is not the death of people that is the main problem, it is the fact that the plants can't grow — there will be almost no food grown in Europe. " [\[29\]](#)

"We are about to take an evolutionary step and my hope is that the species will emerge stronger. It would be hubris to think humans as they now are God's chosen race. " [\[29\]](#)

Lovelock believes it is too late to repair the damage. [\[29\]](#)

Influences of the Gaia hypothesis

Scientific literature

Fritjof Capra, in his fourth book, *The Web of Life*, used Gaia theory to explain the complications and interconnections in the web of life.

Stephan Harding, a student of Lovelock, has written a book, *Animate Earth: Science, Intuition, and Gaia*

John Gribben and Mary Gribben have written a book "James Lovelock - In Search of Gaia" and published by Princeton University Press. ISBN 978-0-691-13750-6. Reviewed briefly in EOS (Trans, AGU), Vol. 90, No. 20, 19 May 2009.

Music

An oratorio by American composer Nathan Currier called *Gaian Variations* was premiered on Earth Day 2004 at Lincoln Center by the Brooklyn Philharmonic, using texts of James Lovelock, Loren Eiseley and Lewis Thomas.

A Heavy Metal/ Folk Rock band from Spain called Mago de Oz has also composed two songs "Gaia" and "La Venganza de Gaia" (Gaia's Revenge) which talk about man and his actions, altering the natural balance on earth. These songs claim that all bad things done to Gaia, will be brought upon man as well, given that we are all part of the same living entity. The Disco Biscuits, from Philadelphia, mention Gaia many times as the central theme in their song "Jigsaw Earth" on their 2002 album *Senor Boombox*

On his 1997 CD release *Hourglass*, Popular American songwriter James Taylor included a song called "Gaia".

The Melodic Death metal band At the Throne of Judgement, on their record "The Arcanum Order", includes a song "Martyrdom, Ruin of Gaia"

In 2009, Kevadbänd has reflected Gaia hypothesis in its hit song "Kasvaja" ("Tumor"), which states that the Gaia organism is suffering from lethal tumor: the human race

American heavy metal band God Forbid included a song entitled "Gaia (The Vultures)" on their 2009 release "Earthsblood".

Movies and television

The film *Virus* features a cyborg that believes humanity to be a virus that has infected its host organism, Earth.

The South Park episode *Lice Capades* addresses the Gaia hypothesis from an ironic standpoint – when one louse suggests that the planet (a child's head) is alive, another louse responds with "If the planet was alive, would it feel this?" and shoots the boy's head – the impact being so minute the boy barely notices.

Edge of Darkness a British television drama serial, produced by BBC Television in association with Lionheart Television International and originally broadcast in six fifty-five minute episodes in late 1985.

In *Final Fantasy: The Spirits Within*, a sci-fi movie, Dr. Sid and his assistant Aki are fierce promoters of the Gaia Theory. Though, in the film, "Gaia" is in reference to the underlying life force within the planet, very similar to the lifestream found in *Final Fantasy VII*.

The series *Eureka Seven* features a planet where coral structure engulfed the planet making it a super organism.

James Cameron's *Avatar* features a Gaia-like network on the planet of Pandora, in which all the organisms have a biological ability to "connect" and share mental communication. This is perhaps a metaphor for the interconnections and systems between organisms and the environment on Earth. The Gaia-like system in *Avatar* is referred to as Eywa, a goddess which the natives worship as a mother earth figure. This reference back to earth and the Gaia Hypothesis is further supported by a scene from the movie where Jake Sully's Avatar, while "praying" to Eywa, says that they (referring to Earthlings) "Killed their mother".

Fiction

A number of works of fiction use the Gaia hypothesis as a central part of the plot. In two of his science fiction novels, *Foundation's Edge* (1982) and *Foundation and Earth* (1984), Isaac

Asimov describes the planet Gaia as one on which all things, living and inanimate, are taking part in a planetary consciousness to an appropriate measure. In Asimov's story Gaia strives for an even greater superorganism that it calls Galaxia, and that comprises the whole galaxy.

In *Lovelock* (1994), a novel by Orson Scott Card & Kathryn H. Kidd, Gaiaology is a fully fledged interdisciplinary science which will soon be put to use by the Earth's first interstellar colony ship. Assuming the target planet will need terraforming, the job of the ship's Gaiaologist will be to integrate the terrestrial species needed for the colonists' survival with the planet's existing ecology. The Gaiaologist's "Witness", a form of assistance animal whose job it is to record every waking moment in the life of such a prominent member of society, is the central character of the book, an enhanced Capuchin monkey named after Lovelock.

The Gaia hypothesis is used extensively by Brian Aldiss in his *Helliconia* Trilogy, where the planets of *Helliconia* and, to a lesser extent, Earth, are presented as the main characters in a story spanning the rise and fall of civilizations as influenced by *Helliconia*'s 2,500-year-long cycle of seasons.

The Gaia hypothesis was also used as a central theme in the novel *Portent*, by James Herbert, in which Lovelock is mentioned by name.

David Brin's novel *Earth* discusses the Gaia hypothesis and features a fictional Gaia ecological movement.

The plot of the novel *Gaia* by David Orrell involves a Gaian cult that intends to purge the Earth of humanity by spreading a bioengineered disease.

American poet, writer and Deep Ecology activist Gary Snyder has a chapter of poems called "Little Songs for Gaia" in his collection of poetry "Axe Handles" (1983).

Games

Maxis has specifically named the Gaia hypothesis and Lovelock as inspirations for their 1990 game, *SimEarth*.

The 1997 console role-playing game, *Final Fantasy VII* features a paradigm of so-called Lifestream, also appearing in the 2001 film, *Final Fantasy: The Spirits Within* as the 'Dr. Sid's Gaia Theory' (these theories look almost identical due to the same scenario writers, Hironobu Sakaguchi and Kazushige Nojima). According to it, all living beings are given some 'spiritual energy' by the spirit of the Planet (Gaia) prior to birth, live out their lives, and then die, with the energy then returning to the Planet. The entire planet (or Gaia) is really a single living organism with its own consciousness and will.

The 2008 Sega title *Sonic Unleashed* contains the character Eggman (Sonic's arch nemesis), fueled with the desire to control the Earth's 'Gaia force' and attempting to crack open the planet to unleash an Evil Entity confined within the Earth's core. Eggman also claims to have studied the 'Gaia Manuscripts'.

The 1999 turn-based strategy PC game, *Sid Meier's Alpha Centauri*, features a living (and eventually sentient) planet in the Alpha Centauri star system. One of the games factions is named "Gaia's Stepdaughters", a group of environmentalists who believe in living with the planet rather than trying to tame or destroy it.

Pop culture

The notion of Gaia has been applied to the networked society and the globalized Internet by cultural theorist Dr. [Michael Strangelove](#) , "Confronted with the inaccessibility of our physical frontiers, my generation has turned inward and discovered two new immanent and infinite frontiers. These new frontiers of the next millennium are the uncensored, distributed self, and cyberspace —the location of the virtual self/community— Electric Gaia."

[\[30\]](#)

See also

- Autopoiesis
- Biocoenosis
- Blue marble
- Earth Science
- Environmentalism
- Gaia spore
- Gaia Thesis
- Geophysiology
- Global brain

- Global Consciousness Project
- Holism
- Hylozoism
- James Kirchner
- Medea hypothesis
- Noosphere
- Permaculture
- SimEarth
- Technogaianism

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