# Gaia hypothesis


The study of planetary habitability is partly based upon extrapolation from knowledge of the Earth's conditions, as the Earth is the only planet currently known to harbour life.

The **Gaia hypothesis**, also known as **Gaia theory** or **Gaia principle**, proposes that all organisms and their inorganic surroundings on Earth are closely integrated to form a single and self-regulating complex system, maintaining the conditions for life on the planet.

The scientific investigation of the Gaia hypothesis focuses on observing how the biosphere and the evolution of life forms contribute to the stability of global temperature, ocean salinity, oxygen in the atmosphere and other factors of habitability in a preferred homeostasis. The Gaia hypothesis was formulated by the chemist James Lovelock and co-developed by the microbiologist Lynn Margulis in the 1970s. Initially received with hostility by the scientific community, it is now studied in the disciplines of geophysiology and Earth system science, and some of its principles have been adopted in fields like biogeochemistry and systems ecology. This ecological hypothesis has also inspired analogies and various interpretations in social sciences, politics, and religion under a vague philosophy and movement.

## Overview

The Gaia theory posits that the Earth is a self-regulating complex system involving the biosphere, the atmosphere, the hydrospheres and the pedosphere, tightly coupled as an evolving system. The theory sustains that this system as a whole, called Gaia, seeks a physical and chemical environment optimal for contemporary life.[1]

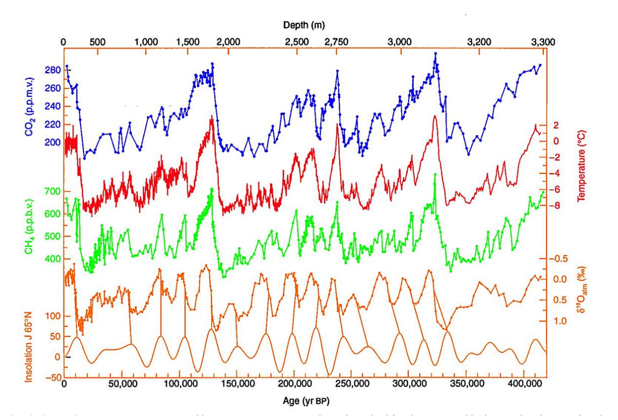
Gaia evolves through a cybernetic feedback system operated unconsciously by the biota, leading to broad stabilization of the conditions of habitability in a full homeostasis. Many processes in the Earth's surface essential for the conditions of life depend on the interaction of living forms, especially microorganisms, with inorganic elements. These processes establish a global control system that regulates Earth's surface temperature, atmosphere composition and ocean salinity, powered by the global thermodynamic desequilibrium state of the Earth system.[2]

The existence of a planetary homeostasis influenced by living forms had been observed previously in the field of biogeochemistry, and it is being investigated also in other fields like Earth system science. The originality of the Gaia theory relies on the assessment that such homeostatic balance is actively pursued with the goal of keeping the optimal conditions for life, even when terrestrial or external events menace them.[3]

## Regulation of the salinity in the oceans

Ocean salinity has been constant at about 3.4% for a very long time.[4] Salinity stability in oceanic environments 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[5] that salinity may also be strongly influenced by seawater circulation through hot basaltic rocks, and emerging as hot water vents on mid-ocean ridges. However, the composition of seawater is far from equilibrium, and it is difficult to explain this fact without the influence of organic processes. One suggested explanation lies in the formation of salt plains throughout Earth's history. It is hypothesised that these are created by bacteria colonies that fix ions and heavy metals during life processes.

## Regulation of oxygen in the atmosphere



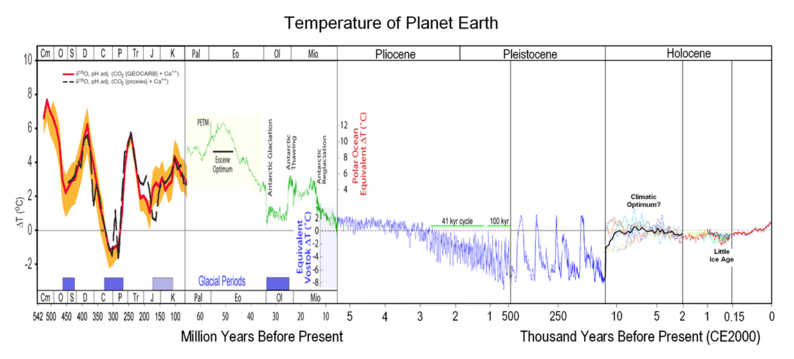
Levels of gases in the atmosphere in 420,000 years of ice core data from Vostok, Antarctica research station. Current period is at the left.

The atmospheric composition remains fairly constant providing the ideal conditions for contemporary life. All the atmospheric gases other than noble gases present in the atmosphere are either made by organisms or processed by them. The Gaia theory states that the Earth's atmospheric composition is kept at a dynamically steady state by the presence of life.[6]

The stability of the atmosphere in Earth is not a consequence of chemical equilibrium like in planets without life. 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)[7] should not exist, as methane is combustible in an oxygen atmosphere.

Dry air in the atmosphere of Earth contains roughly (by volume) 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.039% carbon dioxide, and small amounts of other gases including methane. While air content and atmospheric pressure varies at different layers, air suitable for the survival of terrestrial plants and terrestrial animals is currently known only to be found in Earth's troposphere and artificial atmospheres. Oxygen is a crucial element for the life of organisms, who require it at stable concentrations.

## Regulation of the global surface temperature




Since life started on Earth, the energy provided by the Sun has increased by 25% to 30%;[8] however, the surface temperature of the planet has remained within the levels of habitability, reaching quite regular low and high margins. Lovelock has also hypothesised that methanogens produced elevated levels of methane in the early atmosphere, giving a view similar to that found in petrochemical smog, similar in some respects to the atmosphere on Titan.[9] This, he suggests tended to screen out ultraviolet until the formation of the ozone screen, maintaining a degree of homeostasis. The Snowball Earth[10] research, as a result of "oxygen shocks" and reduced methane levels, that led during the Huronian, Sturtian and Marinoan/Varanger Ice Ages the world to very nearly become a solid "snowball" contradicts the Gaia hypothesis somewhat, although the ending of these Cryogenian periods through bio-geophysiological processes accords well with Lovelock's theory.

Processing of the greenhouse gas $CO_2$, explained below, plays a critical role in the maintenance of the Earth temperature within the limits of habitability.

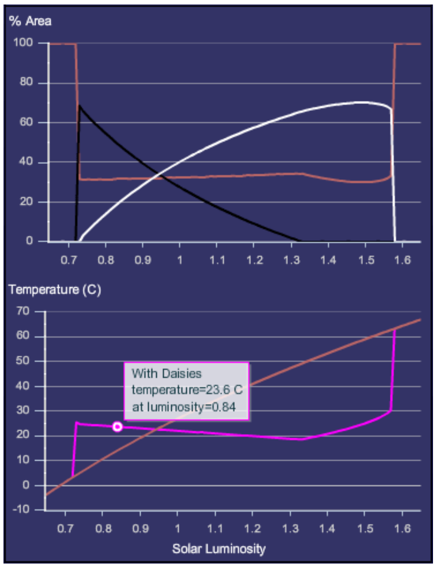
The CLAW hypothesis, inspired by the Gaia theory, proposes a feedback loop that operates between ocean ecosystems and the Earth's climate.[11] The hypothesis specifically proposes that particular phytoplankton that produce dimethyl sulfide are responsive to variations in climate forcing, and that these responses lead to a negative feedback loop that acts to stabilise the temperature of the Earth's atmosphere.

Currently this Gaian homeostatic balance is being pushed by the increase of human population and the impact of their activities to the environment. The multiplication of greenhouse gases may cause a turn of Gaia's negative feedbacks into homeostatic positive feedback. According to Lovelock, this could bring an accelerated global warming and mass human mortality.[12]

### Daisyworld simulations

James Lovelock and Andrew Watson developed the mathematical model Daisyworld, that shows how temperature regulation can arise from organisms interacting with their environment. The purpose of the model is to demonstrate that feedback mechanisms can evolve from the actions or activities of self-interested organisms, rather than through classic group selection mechanisms.[13]

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 the optimum for daisy growth.




Plots from a standard black & white DaisyWorld simulation.

## Biodiversity and stability of ecosystems

The importance of the large number of species in an ecosystem, led to two sets of views about the role played by biodiversity in the stability of ecosystems in Gaia theory. In one school of thought labelled the "species redundancy" hypothesis, proposed by Australian ecologist Brian Walker, most species are seen as having little contribution overall in the stability, comparable to the passengers in an aeroplane who play little role in its successful flight. The hypothesis leads to the conclusion that only a few key species are necessary for a healthy ecosystem. The "rivet-popper" hypothesis put forth by Paul R. Ehrlich and his wife Anne H. Ehrlich, compares each species forming part of an ecosystem as a rivet on the aeroplane (represented by the ecosystem). The progressive loss of species mirrors the progressive loss of rivets from the plane, weakening it till it is no longer sustainable and crashes.[14]

Later extensions of the Daisyworld simulation which included rabbits, foxes and other species, led to a surprising finding that the larger the number of species, the greater the improving effects on the entire planet (i.e., the temperature regulation was improved). It also showed that the system was robust and stable even when perturbed.

Daisyworld simulations where environmental changes were stable gradually became less diverse over time; in contrast gentle perturbations led to bursts of species richness. These findings lent support to the idea that biodiversity is valuable.[15]

This finding was later proved in a eleven-year old study of the factors species composition, dynamics and diversity in successional and native grasslands in Minnesota by David Tilman and John A. Downing wherein they discovered that "primary productivity in more diverse plant communities is more resistant to, and recovers more fully from, a major drought." They go on to add "Our results support the diversity stability hypothesis but not the alternative hypothesis that most species are functionally redundant."[14] [16]

### Processing of $CO_2$

Gaia scientists see the participation of living organisms in the Carbon cycle as one of the complex processes that maintain conditions suitable for life. The only significant natural source of atmospheric carbon dioxide ($CO_2$) is volcanic activity, while the only significant removal is through the precipitation of carbonate rocks.[17] Carbon precipitation, solution and fixation 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 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.

One of these organisms is Emiliania huxleyi, an abundant coccolithophore algae which also has a role in the formation of clouds.[18] $CO_2$ excess is 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 necessary for terrestrial plants. Lately the atmospheric $CO_2$ concentration has increased and there is some evidence that concentrations of ocean algal blooms are also increasing.[19]

Lichen and other organisms accelerate the weathering of rocks in the surface, while the decomposition of rocks also happens faster in the soil, thanks to the activity of roots, fungi, bacteria and subterranean animals. The flow of carbon dioxide from the atmosphere to the soil is therefore regulated with the help of living beings. When $CO_2$ levels rise in the atmosphere the temperature increases and plants grow. This growth brings higher consumption of $CO_2$ by the plants, who process it into the soil, removing it from the atmosphere.

## From hypothesis to theory

James Lovelock called his first proposal the *Gaia hypothesis*. but the term established nowadays is *Gaia theory*. Lovelock explains that the initial formulation was based on observation, but still lacked a scientific explanation. The Gaia Hypothesis has since been supported by a number of scientific experiments[20] and provided a number of useful predictions,[21] and hence is properly referred to as the Gaia theory. In fact, wider research proved the original hypothesis wrong, in the sense that it is not life alone but the whole Earth system that does the regulating.[1]

In 2001, a thousand scientists at the European Geophysical Union meeting signed the Declaration of Amsterdam, starting with the statement *"The Earth System behaves as a single, self-regulating system with physical, chemical, biological, and human components."*[22] In 2005 the Ecological Society of America invited Lovelock to join their Fellowship, and in 2006 the Geological Society of London awarded Lovelock with the Wollaston Medal for his work on the Gaia theory.

Nowadays the Gaia theory is being researched further, mainly in the multidisciplinary fields of Earth system science and biogeochemistry.[23] [24] It is also being applied increasingly to studies of climate change.[25]

**Predictions, tests and results relevant to the Gaia theory. Source: James Lovelock [26]**

| Prediction | Test | Result |
|---|---|---|
| Mars is lifeless (1988) | Atmospheric compositional evidence shows lack of disequilibrium | Strong confirmation, Viking mission 1975 |
| Biogenic gases transfer elements from ocean to land (1971) | Search for oceanic sources of dimethyl sulphide and methyl iodide | Found 1973 |
| Climate regulation through biologically enhanced rock weathering (1973) | Analysis of ice-core data linking temperature and $CO_2$ abundance | Confirmed 2008, by Zeebe and Caldeira |
| Gaia is aged and is not far from the end of its development (1982) | Calculation based on generally accepted solar evolution | Generally accepted |
| Climate regulation through cloud albedo control linked to algal gas emissions (1987) | Many tests have been made but the excess of pollution interferes | Probable for southern hemisphere |
| Oxygen has not varied by more than 5 percent from 21 percent for the past 200 million years (1974) | Ice-core and sedimentary analysis | Confirmed for up to 1 million years ago |
| Boreal and tropical forests are part of global climate regulation | Models and direct observation | Generally accepted |
| Biodiversity a necessary part of climate regulation | By models but not yet in the natural ecosystems | Jury still out |
| The current interglacial is an example of systems failure in a physiological sense (1994) | By models only | Undecided |
| The biological transfer of selenium from the ocean to the land as dimethyl selenide | Direct measurements | Confirmed 2000, Liss |

# 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, such as Ford Doolittle, Richard Dawkins and Stephen Jay Gould.[27] Lovelock has said that by naming his theory after a Greek goddess, championed by many non scientists,[28] 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. Responding to this assertion in 1990, Lovelock stated "Nowhere in our writings do we express the idea that planetary self-regulation is purposeful, or involves foresight or planning by the biota."

Stephen Jay Gould criticised Gaia as merely a metaphorical description of Earth processes.[29] He wanted to know the actual mechanisms by which self-regulating homeostasis was regulated. David Abram argued that Gould was unaware that mechanism was itself only metaphorical.[30] 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 other reasons.[31]

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.[31]

## The Earth alive

The concept of a living Earth has caused a lot of controversy, partly due to the different attributes and connotations given to this hypothetical life, partly because of the straightforward language used by Lovelock in his writings. For instance, evolutionary biologists such as the late palaeontologist Stephen Jay Gould and the ethologist Richard Dawkins attacked his statement in the first paragraph of his book (1979), that "the quest for Gaia is an attempt to find the largest living creature on Earth."[32] James Lovelock sustains that agreeing on a rational answer is not possible because science has not yet formulated a full definition of life.[33]

A basic criterion of the empirical definition of a life-form is its birth out of natural selection and its ability to replicate and pass on its genetic information to a succeeding generation.[34] Dawkins stressed that, consequently, an argument against the idea that Gaia as a living organism is the fact that the planet is not the offspring of any parents and is unable to reproduce.[18]

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, such as E. coli, unable to thrive outside their habitat considered "life", while mitochondria, which have evolved independently from the rest of the cell, are not?

William Irwin Thompson suggests that the Chilean biologist Humberto Maturana and James Lovelock, with the deductive definition of autopoiesis, have provided an explanation for the phenomenon of life.[35] 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.

## Natural selection and evolution

Lovelock accepts a process of systemic Darwinian evolution for such biological feedback mechanisms: creatures that improve their environment for their survival do better than those that damage their environment. However, some scientists dispute the existence of such mechanisms. In 1981, W. Ford Doolittle, in the *CoEvolution Quarterly* article "Is Nature Motherly" argued that nothing in the genome of individual organisms could provide the feedback mechanisms Gaia theory proposed, and 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.

Lynn Margulis, a microbiologist who collaborated with Lovelock in supporting the Gaia hypothesis, argued in 1999, that “Darwin's grand vision was not wrong, only incomplete. In accentuating the direct competition between individuals for resources as the primary selection mechanism, Darwin (and especially his followers) created the impression that the environment was simply a static arena.” She wrote that the composition of the Earth's atmosphere, hydrosphere, and lithosphere are regulated around "set points" as in homeostasis, but those set points change with time.[36]

She also wrote that there is no special tendency of biospheres to preserve their current inhabitants, and certainly not to make them comfortable.[36] According to her, the Earth is a kind of community of trust that can exist at many discrete levels of integration.[36] All multicellular organisms 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.[36]

W. D. Hamilton, one of the greatest evolutionary theorists of the 20th century, called the concept of Gaia Copernican, adding that it would take another Newton to explain how Gaian self-regulation takes place through Darwinian natural selection.[37]

## 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".[38] 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".[38]

Another strong hypothesis is the one called "Omega Gaia".[39] 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 that hold 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 to make conditions more conducive to life, are metaphysical or mystical views for which no evidence exists, and that cannot be tested scientifically. The political branch of Gaia theory 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".

## History

### Precedents

The holistic idea of the Earth as an integrated whole, a living being, has a long tradition. The mythical Gaia was the primal Greek goddess personifying the Earth, the Greek version of "Mother Nature," or the Earth Mother. James Lovelock gave this name to his hypothesis after a suggestion from the novelist William Golding, who was living in the same village as Lovelock at the time (Bowerchalke, Wiltshire, UK). Golding's advice was based on Gea, an alternative spelling for the name of the Greek goddess, which is used as prefix in geology, geophysics and geochemistry.[40]

"Earthrise" taken on December 24, 1968.

In the eighteen century, as Geology consolidated as a modern science, James Hutton maintained that geological and biological processes are interlinked.[41]

Later, the naturalist and explorer Alexander von Humboldt recognized the coevolution of living organisms, climate, and Earth crust.[41] Already in the twentieth century, Vladimir Vernadsky developed theory of the Earth's development that is now one of the foundations of Ecology. The Ukrainian geochemist was one of the first scientists to recognize that the oxygen, nitrogen and carbon dioxide in the Earth's atmosphere result from biological processes. During the 1920s he published works arguing that living organisms could reshape the planets as surely as any physical force. Vernadsky was an important pioneer of the scientific bases for the environmental sciences.[42] His visionary pronouncements were not widely accepted in the West, and some decades after the Gaia hypothesis received the same type of initial resistance from the scientific community.

Also in the turn to the 20th century Aldo Leopold, pioneer in the development of modern environmental ethics and in the movement for wilderness conservation, suggested a living Earth in his biocentric or holistic ethics regarding land.

> It is at least not impossible to regard the earth's parts—soil, mountains, rivers, atmosphere etc,—as organs or parts of organs of a coordinated whole, each part with its definite function. And if we could see this whole, as a whole, through a great period of time, we might perceive not only organs with coordinated functions, but possibly also that process of consumption as replacement which in biology we call metabolism, or growth. In such case we would have all the visible attributes of a living thing, which we do not realize to be such because it is too big, and its life processes too slow.
>
> — Quoted by Stephan Harding in *Animate Earth*.[43]

Another influence for the Gaia theory and the environmental movement in general came as a side effect of the Space Race between the Soviet Union and the United States of America. During the 1960s, the first humans in space could see how the Earth looked alike as a whole. The photograph Earthrise taken by astronaut William Anders in 1968 during the Apollo 8 mission became an early symbol for the global ecology movement.[44]

## Formulation of the hypothesis

James Lovelock, age 91

James Lovelock started defining the idea of a self-regulating Earth controlled by the community of living organisms in September 1965, while working at the Jet Propulsion Laboratory in California on methods of detecting life on Mars.[45] [46] The first paper to mention it was *Planetary Atmospheres: Compositional and other Changes Associated with the Presence of Life*, co-authored with C.E. Giffin.[47] [48] A main concept was that life could be detected in a planetary scale by the chemical composition of the atmosphere. According to the data gathered by the Pic du Midi observatory, planets like Mars or Venus had atmospheres in chemical equilibrium. This difference with the Earth atmosphere was considered as a proof that there was no life in these planets.

Lovelock formulated the *Gaia Hypothesis* in journal articles in the 1970s[38] [49] followed by a popularizing 1979 book *Gaia: A new look at life on Earth*. 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 hypothesis, published in 1979 as *The Quest for Gaia*, began to attract scientific and critical attention.

Lovelock called it first the Earth feedback hypothesis,[28] and it was 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 detecting such combinations in other planets' atmospheres as a relatively reliable and cheap way to detect life.


Lynn Margulis

Later, other relationships such as sea creatures producing sulfur and iodine in approximately the same quantities as required by land creatures emerged and helped bolster the theory.[50]

In 1971 microbiologist Dr. Lynn Margulis joined Lovelock in the effort of fleshing out the initial hypothesis into scientifically proven concepts, contributing her knowledge about how microbes affect the atmosphere and the different layers in the surface of the planet.[23] The American biologist had also awaken criticism from the scientific community with her theory on the origin of eukaryotic organelles and her contributions to the endosymbiotic theory, nowadays accepted. 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 as "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.

## First Gaia conference

In 1985, the first public symposium on the Gaia Hypothesis—Is The Earth A Living Organism? -- was held at the University of Massachusetts August 1–6. The principal sponsor was the National Audubon Society Expedition Institute. Speakers included James Lovelock, George Wald, Mary Catherine Bateson, Lewis Thomas, John Todd, Donald Michael, Christopher Bird, Thomas Berry, Michael Cohen, and William Fields. Some 500 people attended and a concert by Paul Winter concluded the program. The symposium was produced by James A. Swan and Roberta Swan.

## Second 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,[27] 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, *to enable* the flourishing of all life. Strong Gaia, Kirchner claimed, was untestable and therefore not scientific.[51]

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. 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 that produced the responses they desired.[52] Many of these issues were later answered by Lovelock[53] which showed the "Daisyworld model demonstrates that self-regulation of the global environment can emerge from competition amongst types of life altering their local environment in different ways".

Lawrence E. Joseph in his book *Gaia: The Growth of an Idea* argued that Kirchner's attack was principally against Lovelock's integrity as a scientist.[54] Lovelock did not attack Kirchner's views for ten years, until his autobiography "Homage to Gaia", where he calls Kirchner's position *sophistry*.

Lovelock was careful to present a version of the Gaia Hypothesis that 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.

### Third 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 that 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."

### Fourth Gaia conference

A fourth 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. Martin Ogle, Chief Naturalist, for NVRPA, and long-time Gaia Theory proponent, organized the event. 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.

## References

### Online


[1] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 255. ISBN 978-0-465-01549-8

[2] Kleidon, Axel. *How does the earth system generate and maintain thermodynamic disequilibrium and what does it imply for the future of the planet?*. Article submitted to the *Philosophical Transactions of the Royal Society* on Thu, 10 Mar 2011

[3] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 179. ISBN 978-0-465-01549-8

[4] Volk, T. (2002). "Toward a Future for Gaia Theory". *Climatic Change* **52** (4): 423–430. doi:10.1023/A:1014218227825.

[5] Gorham, E. (1991). "Biogeochemistry: its origins and development". *Biogeochemistry* **13** (3): 199–239. doi:10.1007/BF00002942.

[6] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 163. ISBN 978-0-465-01549-8

[7] Cicerone, R.J.; Oremland, R.S. (1988). "Biogeochemical aspects of atmospheric methane" (http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6704984). *Global Biogeochem. Cycles* **2** (4): 299–327. Bibcode 1988GBioC...2..299C. doi:10.1029/GB002i004p00299. .

[8] Owen, T.; Cess, R.D.; Ramanathan, V. (1979). "Earth: An enhanced carbon dioxide greenhouse to compensate for reduced solar luminosity". *Nature* **277** (5698): 640–2. doi:10.1038/277640a0.

[9] Lovelock, James, (1995)"The Ages of Gaia: A Biography of Our Living Earth (W.W.Norton & Co)

[10] Hoffman, P.F. 2001. *Snowball Earth theory* (http://www.snowballearth.org)

[11] Charlson, R. J., Lovelock, J. E., Andreae, M. O. and Warren, S. G. (1987). "Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate" (http://www.nature.com/nature/journal/v326/n6114/abs/326655a0.html). *Nature* **326** (6114): 655–661. Bibcode 1987Natur.326..655C. doi:10.1038/326655a0. .

[12] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, ISBN 978-0-465-01549-8

[13] Watson, A.J.; Lovelock, J.E (1983). "Biological homeostasis of the global environment: the parable of Daisyworld". *Tellus* **35B** (4): 286–9. Bibcode 1983TellB..35..284W. doi:10.1111/j.1600-0889.1983.tb00031.x.

[14] Richard E. Leakey; Roger Lewin (4 November 1996). *The sixth extinction: biodiversity and its survival* (http://books.google.com/books?id=reogHQAACAAJ). Phoenix. pp. 137–142. ISBN 9781857994735. . Retrieved 27 June 2011.

[15] James Lovelock (28 September 2000). *The ages of Gaia: a biography of our living Earth* (http://books.google.com/books?id=xW_T4jV9mFAC&pg=PA215). Oxford University Press. pp. 213–216. ISBN 9780192862174. . Retrieved 27 June 2011.

[16] Tilman, David; Downing, John A. (1994). "Biodiversity and stability in grasslands" (http://www.eeescience.utoledo.edu/Faculty/Gottgens/Conservation Biology/Hans papers 2010/Tilman and Downing 1994 Nature.pdf). *Nature* (Nature Publishing Group) **367** (6461): 363–365. doi:10.1038/367363a0. . Retrieved 27 June 2011.

[17] Karhu, J.A.; Holland, H.D. (1 October 1996). "Carbon isotopes and the rise of atmospheric oxygen" (http://geology.geoscienceworld.org/cgi/content/abstract/24/10/867). *Geology* **24** (10): 867–870. doi:10.1130/0091-7613(1996)024<0867:CIATRO>2.3.CO;2. .

[18] Harding, Stephan (2006). *Animate Earth*. Green Books. ISBN 1-903998-75-1.

[19] *Interagency Report Says Harmful Algal Blooms Increasing* (http://www.publicaffairs.noaa.gov/releases2007/sep07/noaa07-r435.html), 12 September 2007,

[20] J. E. Lovelock (1990). "Hands up for the Gaia hypothesis". *Nature* **344** (6262): 100–2. doi:10.1038/344100a0.

[21] Volk, Tyler (2003). *Gaia's Body: Toward a Physiology of Earth*. Cambridge, Mass: MIT Press. ISBN 0-262-72042-6.

[22] See the full text at Earth system science article.

[23] Turney, Jon (2003). *Lovelock and Gaia: Signs of Life*. UK: Icon Books. ISBN 1-84046-458-5.

[24] Schwartzman, David (2002). *Life, Temperature, and the Earth: The Self-Organizing Biosphere*. Columbia University Press. ISBN 0231102135.

[25] Gribbin, John (1990), "Hothouse earth: The greenhouse effect and Gaia" (Wiedenfield and Nicholson)

[26] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 177. ISBN 978-0-465-01549-8

[27] Turney, Jon. "Lovelock and Gaia: Signs of Life" (Revolutions in Science)

[28] Lovelock, James 2001

[29] Gould S.J. (June 1997). "Kropotkin was no crackpot" (http://libcom.org/library/kropotkin-was-no-crackpot). *Natural History* **106**: 12–21. .

[30] Abram, D. (1988) "The mechanical and the organic: Epistemological consequences of the Gaia hypothesis" (Gaia and evolution: proceedings of the second annual Camelford Conference on the implications of the Gaia thesis)

[31] Lovelock, James (2001), "Homage to Gaia: The Life of an Independent Scientist" (Oxford University Press)

[32] Lovelock, J."Gaia:a new look at life on earth" (Oxford UP:1979,1)

[33] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 192. ISBN 978-0-465-01549-8

[34] Margulis, Lynne and Sagan, Dorion (2000), "What is Life" (University of California Press

[35] Thompson, William Irwin (1988), "Gaia, a way of knowing: political implications of the new biology" (Lindisfarne Press)

[36] Margulis, Lynn. Symbiotic Planet: A New Look At Evolution. Houston: Basic Book 1999

[37] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 195. ISBN 978-0-465-01549-8

[38] Lovelock, J.E.; Margulis, L. (1974). "Atmospheric homeostasis by and for the biosphere- The Gaia hypothesis". *Tellus* **26** (1): 2–10. Bibcode 1974Tell...26....2L. doi:10.1111/j.2153-3490.1974.tb01946.x.

[39] Stages in the Evolution of Gaia (http://www.kheper.net/gaia/Gaia-table.htm), Kheper website (http://www.kheper.net/). Retrieved 14 May 2008.

[40] Lovelock, James. *The Vanishing Face of Gaia*. Basic Books, 2009, p. 197. ISBN 978-0-465-01549-8

[41] Capra, Fritjof (1996). *The web of life: a new scientific understanding of living systems*. Garden City, N.Y: Anchor Books. p. 23. ISBN 0-385-47675-2.

[42] S.R. Weart, 2003, *The Discovery of Global Warming,* Cambridge, Harvard Press

[43] Harding, Stephan. *Animate Eart. Science, Intuition and Gaia*. Chelsea Green Publishing, 2006, p. 44. ISBN 1-933392-29-0

[44] 100 Photographs that Changed the World by Life - The Digital Journalist (http://digitaljournalist.org/issue0309/lm11.html)

[45] Lovelock, J.E. (1965). "A physical basis for life detection experiments". *Nature* **207** (7): 568–570. doi:10.1038/207568a0. PMID 5883628.

[46] Geophysiology (http://www.jameslovelock.org/page4.html)

[47] Lovelock, J.E.; Giffin, C.E. (1969). "Planetary Atmospheres: Compositional and other changes associated with the presence of Life". *Advances in the Astronautical Sciences* **25**: 179–193. ISBN 0-87703-028-6.

[48] Planetary Atmospheres: Compositional and other Changes Associated with the Presence of Life (http://www.jameslovelock.org/page19.html)

[49] J. E. Lovelock (1972). "Gaia as seen through the atmosphere". *Atmospheric Environment* **6** (8): 579–580. doi:10.1016/0004-6981(72)90076-5.

[50] Hamilton, W.D.; Lenton, T.M. (1998). "Spora and Gaia: how microbes fly with their clouds" (http://ejour-fup.unifi.it/index.php/eee/article/viewFile/787/733) (PDF). *Ethology Ecology & Evolution* **10** (1): 1–16. doi:10.1080/08927014.1998.9522867. .

[51] Kirchner, James W. (1989). "The Gaia hypothesis: Can it be tested?". *Reviews of Geophysics* **27** (2): 223. Bibcode 1989RvGeo..27..223K. doi:10.1029/RG027i002p00223.

[52] Kirchner, James W. (2003). "The Gaia Hypothesis: Conjectures and Refutations". *Climatic Change* **58** (1–2): 21–45. doi:10.1023/A:1023494111532.

[53] Lenton, TM; Lovelock, JE (2000). "Daisyworld is Darwinian: Constraints on adaptation are important for planetary self-regulation". *Journal of theoretical biology* **206** (1): 109–14. doi:10.1006/jtbi.2000.2105. PMID 10968941.

[54] Joseph, Larence E (1991), "Gaia: the Growth of an Idea" (St Martin's Press)

### General


- Bondì, Roberto (2006). *Blu come un'arancia. Gaia tra mito e scienza*. Torino, Utet: Prefazione di Enrico Bellone. ISBN 88-02-07259-0.
- Bondì, Roberto (2007). *Solo l'atomo ci può salvare. L'ambientalismo nuclearista di James Lovelock*. Torino, Utet: Prefazione di Enrico Bellone. ISBN 88-02-07704-8.
- Jaworski, Helan (1928). *Le Géon ou la Terre vivante*. Paris: Librairie Gallimard.
- Lovelock, James. *The Independent*. The Earth is about to catch a morbid fever (http://comment.independent.co.uk/commentators/article338830.ece), 16 January 2006.
- Kleidon, Axel (2004). "Beyond Gaia: Thermodynamics of Life and Earth system functioning". *Climatic Change* **66** (3): 271–319. doi:10.1023/B:CLIM.0000044616.34867.ec.
- Lovelock, James (1995). *The Ages of Gaia: A Biography of Our Living Earth*. New York: Norton. ISBN 0-393-31239-9.
- Lovelock, James (2000). *Gaia: A New Look at Life on Earth*. Oxford: Oxford University Press. ISBN 0-19-286218-9.
- Lovelock, James (2001). *Homage to Gaia: The Life of an Independent Scientist*. Oxford: Oxford University Press. ISBN 0-19-860429-7.
- Lovelock, James (2006), interviewed in *How to think about science*, CBC Ideas (radio program), broadcast January 3, 2008. Link (http://www.cbc.ca/ideas/episodes/2009/01/02/how-to-think-about-science-part-1---24-listen/#)
- Lovelock, James (2007). *The Revenge of Gaia: Why the Earth Is Fighting Back — and How We Can Still Save Humanity*. Santa Barbara CA: Allen Lane. ISBN 0-7139-9914-4.
- Lovelock, James (2009). *The Vanishing Face of Gaia: A Final Warning*. New York, NY: Basic Books. ISBN 0-465-01549-8.
- Margulis, Lynn (1998). *Symbiotic Planet: A New Look at Evolution*. London: Weidenfeld & Nicolson. ISBN 0-297-81740-X.
- Marshall, Alan (2002). *The Unity of Nature: Wholeness and Disintegration in Ecology and Science*. River Edge, N.J: Imperial College Press. ISBN 1-86094-330-6.
- Staley M (September 2002). "Darwinian selection leads to Gaia" (http://linkinghub.elsevier.com/retrieve/pii/S0022519302930596). *J. Theor. Biol.* **218** (1): 35–46. doi:10.1006/jtbi.2002.3059. PMID 12297068.
- Schneider, Stephen Henry (2004). *Scientists debate Gaia: the next century*. Cambridge, Mass: MIT Press. ISBN 0-262-19498-8.
- Thomas, Lewis G. (1974). *The Lives of a Cell; Notes of a Biology Watcher*. New York: Viking Press. ISBN 0-670-43442-6.


## External links

- Lovelock: 'We can't save the planet' (http://news.bbc.co.uk/today/hi/today/newsid_8594000/8594561.stm) BBC Sci Tech News
- Interview: Jasper Gerard meets James Lovelock (http://www.timesonline.co.uk/tol/news/article726744.ece)

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