# Gaia Theory

**The Gaia theory holds that Earth's physical and biological processes are inextricably linked to form a self-regulating system that maintains its own habitability. The theory asserts that living organisms and their inorganic surroundings have evolved together as a single living system that greatly affects the conditions of Earth's surface. The theory is often described in terms of Earth acting as a single organism.**

In 1969 the British scientist James Lovelock postulated that life on Earth regulates the composition of the atmosphere to keep the planet habitable. The novelist William Golding, Lovelock's friend and neighbor, suggested Lovelock call the hypothesis Gaia, after the Greek Earth goddess. Although in its early exposition and in the popular press the Gaia hypothesis was understood as saying Earth itself was a living organism, the theory as Lovelock came to articulate it said rather that Earth acts like a living organism, with its living and nonliving components acting in concert to create an environment that continues to be suitable for life.

## Development of the Gaia Hypothesis

The idea that life is more than a passenger on Earth dates back to the work of scholars and researchers in a number of disciplines: the Scottish geologist James Hutton (1726–1797) and was held by the British biologist T. H. Huxley, the animal physiologist Alfred Redfield, the aquatic ecologist G. Evelyn Hutchinson, and the geologist Vladimir Vernadsky. In 1924 Alfred Lotka—a U.S. chemist, ecologist, mathematician, and demographer—first proposed the radical notion that life and the material environment evolved together as a system, but few took him seriously.

In the late 1960s, as part of its search for life on Mars, the National Aeronautics and Space Administration (NASA) gathered information on the composition of planetary atmospheres. Lovelock, then a NASA consultant, noted that Venus and Mars both had atmospheres dominated by carbon dioxide and close to chemical equilibrium. In contrast, gases made by living organisms dominate the atmosphere, which, despite being far from chemical equilibrium, is stable in the long term. Lovelock realized that such stability required a regulator and, since the atmosphere was mainly a biological product, proposed that Earth's collective life forms played this role.

In 1971 he began collaboration with the eminent biologist Lynn Margulis, who brought her extensive knowledge of Earth's microorganisms and added flesh to what was otherwise a chemical hypothesis based on atmospheric evidence.

## Criticism and Refinement of the Gaia Hypothesis

Lovelock and Margulis's joint work brought strong criticism, mainly from other biologists. W. Ford Doolittle and Richard Dawkins, two vocal critics, stated that there was no way for living organisms to regulate anything beyond their individual selves. Some scientists in particular were critical of the hypothesis for being teleological, or assuming that all things have a predetermined purpose. Lovelock responded: "Neither Lynn Margulis nor I have ever proposed a teleological hypothesis" (1990, 100). Doolittle argued that there was nothing in the genome

of individual organisms to provide the feedback mechanisms Gaia Theory proposed. Dawkins has argued that organisms cannot act in concert, as this would require foresight and planning. Stephen Jay Gould, the renowned U.S. paleontologist and evolutionary biologist, wanted to know the mechanisms by which self-regulating homeostasis is possible. This criticism was in the best traditions of science and required a proper response.

In 1981 Lovelock answered the critics by creating the numerical model Daisyworld, an imaginary planet on which there were two species of plant, one light colored and the other dark colored. The planet was warmed by a star that, like Earth's sun, grew hotter as time passed. When the star was cooler, each dark-colored daisy warmed itself by absorbing sunlight, until dark daisies predominated and warmed the planet; as the star grew hotter, each pale-colored daisy, by reflecting sunlight, kept itself and the planet cooler. The competition for space by the two daisy species kept the planet's temperature constant, thus sustaining a habitable condition despite changes in the heat output of the star. The model showed that even without regulating anything other than themselves, organisms and their environment evolve together as a powerful self-regulating system. This demonstration, along with successful predictions of mechanisms for the regulation of the Earth's climate and chemistry, put Gaia on a firm theoretical basis, which was strengthened by a further suite of models from the ecologists Tim Lenton (in 1998) and Stephan Harding (in 1999).

## The Heart of Gaia

Gaia views Earth's surface environment as a self-regulating system composed of all organisms, the atmosphere, oceans, and crustal rocks, which sustains conditions favorable for life. It sees the evolution of life and the evolution of Earth's surface and atmosphere as a single process, not separate processes, as taught in biology and geology. Organisms evolve by a process of natural selection, but in Gaia, they do not merely adapt to the environment, they change it. Humans, clearly, are changing the atmosphere, the climate, and the land surfaces, but other organisms, mostly microscopic, have in the past made changes that were even more drastic. The appearance of oxygen in the air two billion years ago is but one of them. Gaia stands to Darwinism somewhat as relativity theory stands to Newtonian physics. It is no contradiction of Darwin's great vision but an extension of it.

What use is Gaia? It has been a fruitful source of new research and an inspiration for environmentalists. It led to the discovery of the natural compounds dimethyl sulfide and methyl iodide, which transfer the essential elements sulfur and iodine from the oceans to the land. It showed how life in the soil and on the rocks increases the rate of removal of carbon dioxide from the air and so regulates both the levels of carbon dioxide and, consequently, climate. Its most daring prediction stated in 1987 by Robert Charlson, Lovelock, Meinrat Andreae, and Stephen Warren, was that the microscopic algae of the oceans are linked by their emission of a gas, dimethyl sulfide, with the clouds and with the climate. As Earth gets hotter, the theory says, these algae release more dimethyl sulfide into the atmosphere, which increases Earth's cloud cover, which in turn cools the Earth: without clouds, the earth would be hotter by 10–20°C. This idea is crucial to the proper understanding of climate change. The authors received the Norbert Gerbier Prize and medal from The World Meteorological Office for this theory in 1988. Ten years later hundreds of scientists worldwide were studying the links between ocean algae, atmospheric chemistry, clouds, and climate. Climatologists and even physiologists have used Daisyworld in their research. Over the years, Gaia has changed the way scientists think. There is no better example of this change than the Amsterdam Declaration of 2001. A conference of environmental scientists in 2001 issued the declaration, which had as its first bullet point: "The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components" (Open Science Conference 2001). Although not yet a full statement of Gaia theory, it a substantial advance on the separated view of earth and life sciences that went before.

In recent years, the Gaia theory has become part of general discussion and popular journalism, especially in relation to global climate change. Its subject, the complex interdependencies of planetary life, is part of the academic curriculum under the name "Earth Systems Science."

## The Revenge of Gaia

In a 2006 book, Lovelock made the argument that environmental degradation and climate change are testing Gaia's capacity to self-regulate and maintain Earth's habitability. He believes that it is already too late to avoid significant climate change, thus rendering large portions of our planet much less hospitable for humans. Sustainable development and renewable energy are two hundred years too late to be of much help; it is now time to direct greater efforts towards adaptation. Lovelock is an advocate of nuclear power as a short-term solution for maintaining energy demands, but other clean alternative energy sources are thought to be too little too late. Given the range of environmental stresses, he claims that human civilization will find it difficult to survive as is, with the human population experiencing significant decline during the next hundred years. Lovelock claims that Gaia's self-regulation is likely to prevent any catastrophic wipeout of life on Earth, but the present course of action is unsustainable, and there will be changes to life on Earth one way or the other.

James LOVELOCK
*European Communities Information Office*

*See also* Anthroposphere; Biological Exchanges; Climate Change; Environmental Movements; Universe, Origin of

### Further Reading

Charlson, R. J., Lovelock, J. E., Andreae, M. O., & Warren, S. G. (l987). Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature*, *326*(6ll4), 655–66l.

Crist, E., & Rinker. H. B. (Eds.) (2009). *Gaia in turmoil: Climate change, biodepletion, and Earth ethics in an age of crisis*. Cambridge, MA: MIT Press.

Harding, S. P. (1999). Food web complexity enhances community stability and climate regulation in a geophysiological model. *Tellus*, *51*(B), 815–829.

Lenton, T. (1998). Gaia and natural selection. *Nature*, *394*, 439–447.

Lotka, A. (1956). *Elements of mathematical biology*. New York: Dover. (Original work published 1924)

Lovelock, J. E. (1969). Planetary atmospheres: Compositional and other changes associated with the presence of life. In O. L. Tiffany & E. Zaitzeff (Eds.). *Advances in the astronautical sciences* (Vol. 25, pp. 179–193). Tarzana, CA: American Astronautical Society.

Lovelock, J. E. (1979). *Gaia: A new look at life on earth*. Oxford, U.K.: Oxford University Press.

Lovelock, J. E. (1988). *The ages of Gaia: A biography of our living earth*. New York: W.W. Norton.

Lovelock J. E. (1990). Hands up for the Gaia hypothesis. *Nature*, *344*, 100–102.

Lovelock, J. E. (1991). *The practical science of planetary medicine*. London: Gaia Books.

Lovelock, J. E. (2006). *The revenge of Gaia: Earth climate crisis & the fate of humanity*. New York: Basic Book.

Lovelock, J. E. (2008). *The vanishing face of Gaia: A final warning*. New York: Basic Books.

Lovelock, J. E., & Margulis, M. (1973). Atmospheric homeostasis by and for the biosphere: The Gaia hypothesis. *Tellus*, *26*, 2–10.

Lovelock, J. E., & Watson, A. J. (l982). The regulation of carbon dioxide and climate: Gaia or geochemistry. *Planet. Space Science*, *30*(8), 795–802.

Open Science Conference (2001, July 10–13).The Amsterdam declaration on global change. Retrieved September 5, 2002, from http://www.sciconf.igbp.kva.se/Amsterdam_Declaration.html

Watson, A. J., & Lovelock, J. E. (l983). Biological homeostasis of the global environment: The parable of Daisyworld. *Tellus*, *35*(B), 284–289.