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The Concept of ‘Gaia’

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*Introductory

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Abstract

The Gaia theory of James Lovelock proposes that the Earth is a self-regulating system, or super-organism, maintaining conditions hospitable to contemporary planetary biota. Objections to this theory, concerning its alleged untestability and circularity, are considered and countered. Favourable evidence includes Lovelock’s daisyworld model of a planet regulating its own temperatures and thus maintaining homeostasis, and his discoveries of actual regulatory mechanisms such as the biological generation of dimethyl sulphide, which removes sulphur from the oceans and seeds clouds whose albedo reduces solar radiation (a negative feedback mechanism). After some decades of scepticism, sections of the scientific community have partially endorsed Gaia theory, accepting that the Earth system behaves as if self-regulating. Whether or not this theory is acceptable in full, it has drawn attention to the need for preserving planetary biological cycles and for the planetary dimension to be incorporated in ethical decision-making, and thus for a planetary ethic.

Key words

Daisyworld model; dimethyl sulphide; feedback mechanisms; Gaia; homeostasis; Lovelock, James; planetary ethic; self-regulating system; super-organism; testability

Key concepts

James Lovelock hypothesises that the planetary physical and biological system is a self-regulating super-organism.

There were precedents before Lovelock for ascribing life either to the planet or to the universe.

James W. Kirchner presents Gaia hypotheses as either unoriginal or untestable.

Lovelock demonstrates that Gaia theory is both original and testable, albeit indirectly.

Lovelock’s theory can readily escape the charge of circularity.

Predictions of Gaia theory include the existence of biologically generated mechanisms of planetary regulation.

Lovelock’s discovery of dimethyl sulphide discloses such a mechanism for the regulation of oceanic sulphur.

Both atmospheric oxygen and atmospheric nitrogen turn out to be biologically generated and maintained.

Philosophers such as Stephen Clark and Mary Midgley have made Gaia a symbol for the planetary thinking currently needed.

The Amsterdam Declaration of planetary scientists (2001) accepted aspects of Gaia theory, without explicitly accepting the theory's planetary goal.

Introduction

The Gaia Theory claims that the Earth is a self-regulating system, maintaining the conditions that support life. Its author, James Lovelock, has proposed since the late 1960s that the explanation of phenomena such as the long-standing constancy of the proportion of oxygen in the atmosphere and of the salinity of the oceans is that the complex system of life on our planet ensures its own continuation, or, latterly, that this is brought about by planetary life together with its environment of atmosphere, rocks and oceans. He does not officially claim that this system, which he calls 'Gaia', acts knowingly or purposively, but he does regard it as a super-organism with wide-ranging capacities for self-repair. The name 'Gaia' is borrowed from that of the ancient Greek goddess of the Earth, the consort of Uranus (Heaven), and the mother of seas, mountains and living creatures. This name was originally suggested to Lovelock by the novelist, William Golding.

Lovelock's developing stance

While researching (with NASA) whether either Mars or Venus could sustain life, Lovelock devised the test of whether their climates reflected the equilibrium that could be predicted to arise from physical forces alone, or deviations from such an equilibrium, which might be generated by the presence of life. He concluded that whereas these other planets displayed just such an equilibrium, our own planet, by contrast, deviates therefrom and maintains an unexpected constancy or homeostasis of the proportions of gases in the atmosphere and salts in the oceans, ascribable to nothing but life itself. These conclusions led him to propound the Gaia Hypothesis that life on Earth keeps these proportions constant and thus hospitable for whatever is the contemporary ensemble of organisms. Later this hypothesis was refined as the Gaia Theory, which represents not just life on Earth but life in conjunction with surface rocks, the ocean and the atmosphere as a self-regulating system, with a goal – 'the regulation of surface conditions so as always to be as favourable as possible for contemporary life' (Lovelock, 2006, 208). Early objections, such as that the oxygen generated by plants and algae is disadvantageous to anaerobic life, and thus that not all life can be included in the Gaian system, were countered by including anaerobic life, together with the conditions that support it, as key regulators in the planetary system of Gaia.

Predecessors

Lovelock was not the first to present the Earth as a super-organism. As Lovelock acknowledges (Lovelock, 1990, 101), James Hutton hit on this intuition in 1788, holding that the Earth could only be studied properly by planetary physiology; this has led Lovelock to propose the study of Gaia as 'geophysiology'.

Much earlier, Plato's *Timaeus* (fourth century BCE) represented the world as a living organism, albeit one produced by a divine Artificer, and subsequently the Stoics, from Chrysippus (third century BCE) onwards, treated the active substance of the universe as a world-soul or as reason, imposing form on passive matter. These speculative systems, unlike Lovelock's work as a scientist, were much more extensive in scope than Lovelock's theory, and depended neither on empirical evidence nor on thought-experiments. Yet they may have predisposed those familiar with these traditions to the cogency of scientific theories of the Earth such as those of Hutton and of Lovelock, who was himself not slow to gain mileage for his theory by referencing Gaia, the Earth Mother of the ancient Greeks (Lovelock, 2006, 29).

Implications for ecological priorities

Lovelock has long suggested that the current general concern of environmentalists about pollution and the side-effects of technology is exaggerated, partly because of the resilience of Gaia and its ability to withstand such challenges. In particular, he used to doubt whether chlorofluorocarbons were a major problem (diverging here from the international concern which led to the crucial Montreal Protocol of 1987), and he continues to be an advocate of nuclear energy. But he is concerned about human interference with two kinds of global region, continental shelves, whose biota play key roles such as regulating and limiting the sulphur of the oceans, and the tropics, where the burning of grasslands emits 'a huge burden of aerosol particles', together with the bulk of the chlorine now in the atmosphere in the form of methyl chloride. Thus it is not advanced technology that, in his view, causes ecological harm but traditional husbandry and the associated traditional technology. One form of high technology that he favours is the emission of sulphate aerosols into the stratosphere, to reduce incoming solar energy and thus protect Gaia by averting global warming (Lovelock, 2006, 167); yet such 'Solar Radiation Management' could risk the acidification of the atmosphere and thus of rainfall, and could be regarded as an aberration from rather than an implication of Gaia Theory. And while accepting that the planet could support a larger human population, he (perhaps wisely) endorses the view that the optimum number of people is not as large as the maximum that Earth can support (Lovelock, 1979, 122), and that population increase may need to be halted at not far above 10 billion people, or at a still lower level.

Daisyworld

At one stage, the main evidence for the Gaia Theory was Lovelock's thought-experiment 'Daisyworld'. This thought-experiment showed how a planet with just two species, dark- and light-coloured daisies, could (through traits such as albedo or reflectivity) regulate its own temperature, even if the energy from a nearby star, such as our Sun, were gradually increasing over time (Watson and Lovelock, 1983). The Daisyworld thought-experiment showed that climate regulation by two or more species was possible, but left large questions unanswered about whether relevant mechanisms of regulation were actually to be found, and whether such self-regulation was to be understood as purposive or not.

Lovelock later presented this thought-experiment as, *inter alia*, a reply to the criticism of Richard Dawkins that there is no way of reconciling evolution by natural selection with the Gaia hypothesis (Dawkins, 1982). The evolution of the daisies is 'tightly coupled' to the planetary albedo, each affecting the other (Lovelock 1990); hence evolution by natural selection and Gaia theory are compatible after all. A more detailed reconciliation has been offered by Tim Lenton (1998), who explains, on the strength of variations on the daisyworld model, how self-regulation at planetary level can arise from natural selection at individual and local level, while accepting that ‘environmental regulation can only emerge from traits that are more beneficial than costly to the individual’ (Lenton, 1998, 8).

Lenton acknowledges that defenders of Gaia theory, ‘when asked to explain how planetary self-regulation could have arisen, … are in much the same position as Darwin when asked how the eye could have evolved’. Yet the way organisms alter their environment ‘means that there is an inevitable feedback connection between the living and the non-living’, in which, in some circumstances, impacts of organic processes enhance growth conditions for both the organism and for systems to which it belongs. In other circumstances, such processes can exacerbate e.g. the adverse impacts of growing solar radiation, but vegetation in particular ‘almost always influences climate for its own benefit’ (Lenton, 1998, 9 and 13). On Darwin, see also: DOI: 10.1038/npg.els.0002397 .

Kirchner’s five hypotheses

In an address of 1988, first published in 1992, James W. Kirchner presented five hypotheses as variants on Lovelock's original hypothesis, in an attempt to clarify what was at issue. Some of these five hypotheses are relatively uncontroversial, but weak in terms of their originality and distinctiveness, while the others, he suggests, are untestable and thus fall short of Popperian standards for contributions to science.

Kirchner playfully devises distinctive names for his five hypotheses, calling his first hypothesis 'Influential Gaia', which asserts that the biota influence aspects of the abiotic world, and his second, 'Coevolutionary Gaia', which maintains that the biota and the abiotic environment influence each other. These hypotheses, he remarks, had long been held before Lovelock’s time, by nineteenth-century theorists such as Spencer, Darwin and Huxley.

Before turning to his remaining hypotheses, Kirchner discusses the possibility that Gaia could merely be a metaphor, for which the Earth is to be seen as a living organism. But this potentially fruitful thought would not even so qualify as a scientific hypothesis, which would require empirical testability. However, the defenders of Gaia insist on its status as an hypothesis, and not just an unscientific metaphor. To express the forms this hypothesis might take, he examines three further hypotheses, beginning with ‘Homeostatic Gaia’, the theory that the biota influence the abiotic world in a stabilizing manner.

Kirchner questions the meaning of ‘stabilizing’ and thus of Gaia’s 'Homeostatic nature', and casts doubt on whether this claim has an empirical basis; he appeals here to the apparently destabilizing role of the Precambrian anaerobic biota with their emissions of (poisonous) oxygen. This objection can be answered along the lines of Lovelock's clarification of 1990. Lovelock did not in fact claim that 'the Precambrian blue-green algae were not Gaian because they were so violently destabilizing' (Kirchner 1992:150). Lovelock's claim cannot be accused of making the stabilizing role of Gaia a tautology, granted that anaerobic life was included as a part of Gaia (Lovelock, 1990). Indeed the constancy of the proportion of oxygen in the atmosphere ever since the Precambrian period supplies impressive (if not entirely conclusive) empirical evidence of Gaia’s overall stabilizing role.

Kirchner's fourth hypothesis, 'Teleological Gaia', claims that the atmosphere is not only kept in homeostasis by the biota but that this is contrived for the sake of the biota. Kirchner, however, holds that the implicit purpose is left undefined, and makes the valid point that the stability of the percentage of oxygen cannot be claimed to have been contrived. Nevertheless the sustained percentage of oxygen clearly enables the survival of most (if not quite all) life, and, while Lovelock could not indeed know its intended purpose, perhaps the quasi-purposive survival of oxygen-dependent life is what matters. The fact that most life survives due to sustained oxygen levels (whether contrived or not) can apparently still be explained by the Gaia theory.

Kirchner's fifth and final hypothesis, 'Optimizing Gaia', maintains that the assemblage of biota moulds or manipulates its physical environment for the purpose of creating biologically optimal conditions for itself. Here Kirchner questions the ability of the biota to preserve conditions optimal for the many different forms of life, including anaerobic life and oxygen-dependent life, and casts doubt on the very concept of optimal conditions for life in general. Yet pre-oxygen life has survived alongside oxygen-dependent life in the conditions that have prevailed since the Precambrian period, and the planet may manifest conditions favourable not only to particular organisms but also to whole systems, and systems of systems. And while Kirchner's problem with representing optimality as a purpose remains, Lovelock's move from his original Gaia hypothesis (with the biota as the main agent) to the Gaia theory (where the biota and the abiotic environment both exercise agency) draws much of the sting from Kirchner's objection to the assemblage of biota manipulating the environment into becoming optimal for itself. For feedbacks can and sometimes do generate conditions advantageous to the growth of whole ranges of species (Lenton 1998), and even if this is not a purposive contrivance of optimality, the possibility remains of evolution developing as if this were just what is taking place.

Testability

Kirchner suggests that, except in their weaker and less controversial forms, Gaia hypotheses are untestable. To this objection, Lovelock replied with a whole table of relevant tested predictions of his theory (Lovelock, 1990, 102). For example, the prediction that organisms make compounds that can transfer essential elements from oceans to land surfaces was confirmed by his discoveries of the production by bacteria of dimethyl sulphide (which regulates the proportion of sulphur in oceans) and of methyl iodide (which regulates the proportion of iodine) (Lovelock, Maggs and Rasmussen, 1973). His further prediction that biologically enhanced rock weathering promotes climate regulation by control of CO_2 was confirmed by the discovery that micro-organisms greatly increase rock weathering, thus controlling atmospheric CO_2 levels. (Schwartzman and Volk, 1989). Accordingly the Gaia theory turns out to be at least as testable as the nuclear winter theory with which Kirchner contrasts it (Kirchner, 1992, 152). The two theories turn out to be tragically testable in parallel ways, for a further test of the Gaia theory would arise if rainforests and estuary life were largely to be destroyed and their regulatory functions lost.

The discovery of dimethyl sulphide subsequently led to the devising of the CLAW hypothesis, named after its four originators, Robert Jay Charlson, James Lovelock, Meinrat Andreae and Stephen G. Warren. This hypothesis proposes that the phytoplankton that produce dimethyl sulphide are responsive to variations in solar radiation, and that the resulting responses generate negative feedback, the effect of which is to stabilize the temperature of the Earth's atmosphere. Increasing solar radiation increases the photosynthesis and thus the growth of these phytoplankton and their production of dimethyl sulphide, which then enters the atmosphere, and is oxidized to form sulphur dioxide. Sulphate aerosols are in turn produced which generate clouds and thus cloud albedo, which increases the reflection of sunlight, and decreases the radiation with which this chain of events began. In this way increases in solar radiation can be counteracted by the negative feedback loop that they generate (Charlson et al, 1987). This hypothesis is manifestly testable, and the mechanism that it proposes supplies just the kind of regulatory phenomenon that the Gaia hypothesis predicts.

More recently, Lovelock has further proposed the anti-CLAW hypothesis, in which a positive feedback loop is generated. Increasing oceanic temperatures could decrease the supply of nutrients to phytoplankton and cause a reduction in the production of dimethyl sulphide; and this in turn could reduce cloud formation and cloud albedo, leading to reduced reflection of solar radiation and further increases in atmospheric and oceanic temperatures, alongside greater and greater reductions in the production of dimethyl sulphide (Lovelock, 2006). This too is an all-too-testable hypothesis, that brings to light the potential vulnerability of Gaian mechanisms, which may well have, thus far, maintained the stability of the temperatures of both the oceans and the atmosphere.

The 'circularity' objection

One longstanding objection to the Gaia theory accuses it of circularity. In the words of Michael Allaby, 'the existence of Gaia is introduced to explain the hospitable environment and the hospitable environment proves the existence of Gaia' (Allaby, 1996, 7). But Lovelock need not accept the latter claim. This is partly because he need not treat particular regulatory mechanisms (such as dimethyl sulphide) as proofs, and partly because he recognises that natural cycles under some conditions generate positive feedback loops detrimental (rather than hospitable) to current biota. Gaia theory is thus (as Allaby recognises) more nuanced than the circularity objection allows for, and proves scientifically useful in suggesting many more directly testable hypotheses not previously envisaged by scientists.

Cybernetic control of atmosphere and oceans

For Lovelock, Gaia normally exerts a cybernetic control over the proportions and the temperature range of the atmosphere and the oceans, but envisages circumstances under which human interventions could cause this cybernetic control to break down. In 1979 the example he gave was the runaway effects of the imaginary deliberate introduction of a bacterium capable of fixing atmospheric nitrogen and transforming it into fertilising nitrates (Lovelock, 1979, 42-45). By 2006 he had no need of an imaginary scenario of anthropogenic change, seeing global warming as already potentially poised to subvert Gaian systems (Lovelock, 2006).

Gaian systems, in his theory, sustain the level of atmospheric oxygen at around 21%, just too low for widespread conflagrations to be triggered and sufficiently high to allow of animal respiration. Methane is, like oxygen, a biological product, and plays a part in stabilising oxygen levels in the atmosphere, counteracting the effects of the burial of carbon (from which a surplus of oxygen results), as methane, on being released from soil by bacteria, is itself oxidised in the lower atmosphere (Lovelock, 1979, 69-74).

Atmospheric nitrogen turns out to be yet another biological product, produced by denitrifying bacteria. In the absence of life, atmospheric nitrogen would return to the oceans in nitrate form, where it could well cause the level of salinity to become too high for life; but in the atmosphere it serves to dilute oxygen and help prevent the proportion of atmospheric oxygen becoming too high (Lovelock, 1979, 78-79).

Meanwhile iodine, which is necessary for animal life, is returned from the oceans to the land through the growth of kelp, while oceanic chlorine reacts with biologically generated methyl iodide to produce methyl chloride, which regulates atmospheric ozone (Lovelock, 1979, 104-5)

The discoveries of other scientists such as Schwartzman and Volk, supplemented by Lovelock’s own discoveries of the regulation of oceanic sulphur and iodine, illustrate the way in which the planetary system appears to behave in a self-regulating manner. But we should not infer that the system is a purposive one, despite Lovelock’s occasional recourse to language about purposiveness and intelligence (Lovelock, 1979, 146).

Relation to argument from fine-tuning

To some, Gaia theory may appear to conflict with the fine-tuning argument, which appeals to the way in which the universe appears to be fine-tuned to the emergence and survival of life. For Gaia theory implies that, rather than the abiotic Earth having conditions that were antecedently hospitable to life (as in the story of Goldilocks), living organisms are instead to be understood as transforming the planet into habitability.

There is, however, no real conflict, for the fine-tuning argument appeals not so much to particular conditions of our planet as to cosmic or universal constants, minuscule variations of which would have prevented the appearance of living organisms (Davis, 1997). Physical laws of nature have in fact facilitated the emergence of life, and, if Gaia theory is to be credited, life has then generated and (largely) maintained conditions on Earth favourable to itself. Hence endorsement of Gaia theory turns out to be consistent with the fine-tuning argument after all.

Influence of Gaia as a symbol

Gaia has been widely used as a symbol to epitomise either loyalty to the planet or the need for a global perspective. Two philosophers who have written along these lines are Stephen R.L. Clark and Mary Midgley.

Clark advocates a form of metaphysical holism, in which what is real is not individuals but the whole, of which Gaia is the most magnificent subsystem. Individuals are, by contrast, ‘patterns of relationships’, which are to be respected, as recommended by Aldo Leopold, as fellow-creatures on the basis of a sense of kinship. We exist only as elements of a continuing community, and should follow the maxim 'Take no more than your share, no more than you must to sustain the particular value that you carry for the whole'. Clark's is a controversial metaphysic, and Lovelock's followers have no need to subscribe to it; but the ethic that Clark commends could contribute to the kind of Gaian thinking that accords much greater priority than hitherto to maintaining the biotic and other systems of the planet.

Midgley's concern is to replace social thinking turning on individualism and imaginary social contracts with Gaian thinking which takes into account systemic and planetary goods. Individualism (as a theory of motivation) often represents altruistic concern as either misguided or impossible, while contract theory cannot perforce take into account the importance of systems, collectives and traditions, let alone future generations. Yet love of collective entities such as club, church or country is frequently a significant motive in human affairs, and motivations of this kind will need to be fostered if humanity is to avoid irreversible damage to planetary systems. She is also concerned to reconcile Gaian thinking with Darwinism, quoting Tim Lenton as saying that 'A trait that brings the resulting organism closer to the optimum growth conditions will spread' (Lenton, 1998, 9; Midgley, 2001, 38), as an explanation of the persistence and spread of traits such as photosynthesis, beneficial both to their possessors and to other creatures, and thus of the feasibility of ecosystems that depend on such traits, and of the planetary system that depends on such systems. But maintaining both ecosystems and the planetary system has become increasingly important, now that they are under threat; and for Midgley it takes Gaian thinking rather than traditional attitudes to grasp this importance and embody it in action. On altruism, see also: DOI: 10.1002/9780470015902.a0003442.pub2 .

From the perspective of Gaian thinking in Midgley's sense, it would not matter unduly if the Gaia theory were in some respects misguided (for example with regard to its claims about Gaia having a goal); what is important about it is how it transforms our thinking away from traditional individualism and towards broader, more planetary loyalties.

Conclusion

Partial recognition of the Gaia theory can be found in the Amsterdam Declaration on Earth System Science of 2001, a declaration of four global change research programmes, which states that 'The Earth system behaves as a single, self-regulating system, comprised of physical, chemical, biological and human components' (Amsterdam Declaration, 2001). Advocates of Gaia theory are disappointed by these scientists' omission to endorse what advocates of Gaia claim is the cybernetic goal of this system, along with their view that the planet is effectively a superorganism. But even if the Earth is not a superorganism, the Gaia-inspired discovery of regulatory mechanisms including the biological generation of dimethyl sulphide may disclose processes that human beings should not interfere with, as well as underlining the importance of curtailing anthropogenic greenhouse gas emissions. As the Amsterdam declaration avers, an ethical framework for global stewardship and strategies for Earth System management are urgently needed, little as Lovelock, a critic of 'stewardship' ethics, would endorse this claim. The Gaia theory is in any case serving in multiple ways, some of them symbolic, to disclose the vital need for the planetary impact of past and present industrial, agricultural and energy policies to be taken into account.

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Glossary

dimethyl sulphide: this is the indirect product of certain phytoplankton, often situated in estuaries or on continental shelves, which synthesise dimethylsulphoniopropionate; this substance, on breakdown, produces dimethyl sulphide, first in seawater and then in the atmosphere, where it is oxidised to form sulphur dioxide. This process controls the level of sulphur in the oceans. According to the CLAW hypothesis (see text), the resulting aerosols then seed clouds, the albedo of which reflects back much solar radiation and decreases the solar radiation that reaches the surface of the Earth.

fine-tuning argument: this is a variant of the design argument for the existence of God as universal creator. It appeals to features of the universe that facilitate the existence of life, including characteristics of planetary systems, and also universal constants, minuscule changes in the value of which would make life impossible.

Gaia hypothesis: the hypothesis of James Lovelock and Lynn Margulis, postulated in the early 1970s, that ‘life on earth keeps the surface conditions always favourable for whatever is the contemporary ensemble of organisms’. Lovelock now regards this hypothesis as false, adding that it later evolved into Gaia Theory (Lovelock, 2006, 208).

Gaia Theory. ‘A view of the Earth that sees it as a self-regulating system made up from the totality of organisms, the surface rocks, the ocean and the atmosphere tightly coupled as an evolving system. The theory sees this system as having a goal – the regulation of surface conditions so as always to be as favourable as possible for contemporary life.’ (Lovelock, 2006, 208) greenhouse gas emissions: anthropogenic emissions of gases including carbon dioxide, methane, water vapour, nitrous oxide and chlorofluorocarbons which are partially opaque to radiation of longer wavelengths and which keep surface air warmer than it would otherwise be in the absence of these gases. Since the industrial revolution these emissions have increased so that carbon-equivalent levels of gases have increased from 280 parts per million (ppm) to over 400 ppm.

homeostasis: the tendency of a system to maintain constancy of its own states within a small range of values by resisting or adjusting to change. Examples include the stable temperature of the bodies of living human beings, and, if the Gaia Theory is correct, the stability of the proportions of atmospheric gases and of oceanic salinity.

negative feedback: the negative feedback of an unwanted occurrence or process counteracts or corrects that occurrence or process, as when the driver of a car steers it to compensate for deviation from its intended trajectory. When increased solar radiation initiates a process that reduces its warming of the surface of the Earth, this is an example of negative feedback. If the radiation instead initiates a process that serves to increase its impact on the Earth’s surface, this is an example of positive feedback.