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Frogs have proven both resilient and adaptive as well as sensitive to changing global environments since the advent of terrestrial forest ecosystems. At left, *Rana pueyoi*, from the Miocene of Spain became extinct without human intervention. At right, this Northern Corroboree Frog (*Pseudophryne pengelleyi*), resting on Sphagnum moss burnt during bushfires that devastated Alpine ecosystems in the mountains of southeastern Australia, is threatened by the impacts of climate change, disease and habitat loss. However, humans are also allocating substantial funding its survival – currently about 10,000 € per frog! Photos: Peter Sorjonen-Ward (left) and Ben Scheele, Australian National University (right).

Hiilikaudesta asti sammakkoeläimet ovat edustaneet selviytyjiä, jotka viestivät maapallon tilasta ja muutoksista. Mioseenina Espanjassa elänyt *Rana pueyoi* (vas.) kuoli sukupuuttoon ilman ihmisen vaikutusta. *Pseudophryne pengelleyi* (oik.) elää vain kaakkois-Australian vuoristoissa ja on uhanalainen chytrid-taudin sekä ilmaston lämpenemisen takia. Tämä yksilö lepää hiiltyneen sammaleen päällä selviyttyään vuoden 2020 metsäpaloista. Ihminen osallistuu lajin suojelemiseen – jopa 10 000 eurolla sammakkoa kohti! Kuvat: Peter Sorjonen-Ward (vas.) ja Ben Scheele (oik.).

Changing climate and responses – A Gaian Earth systems perspective

PETER SORJONEN-WARD

Planet Earth and our human species are now living in a relationship that is turbulent and potentially destructive, rather than benign, respectful, and sustainable. Humanity is increasingly confronted with multiple crises and issues of concern, from the atmospheric to the nanoscale and over equitable and sustainable access to ecological,

mineral and energy resources. The legacy and role of scientific inquiry and analysis, along with the exponentially expanding acquisition of data monitoring the state of the planet and its resources, should continue to be seen as a source of encouragement, especially in an environment where anxiety and despair, or deliberate disinformation prevail.

The rise of science and emerging awareness of global human impact

The foundations of empirical science, based on systematic investigations of the natural world, emerged some five centuries ago. This happened through the astronomical observations, physical experiments, and insights of pioneering scientists such as Leonardo da Vinci, Nikolaus Copernicus, Galileo Galilei, Tycho Brahe, and Robert Boyle. Together with mathematical formulations and syntheses by René Descartes, Isaac Newton, and Gottfried Leibniz, this provided humanity with a comprehensive, mechanistic framework for understanding the place of the Earth within the cosmos. This reductionist, experimental approach to studying physical processes, and development of a deterministic worldview, coincided with the onset of global trade, which was in turn advanced by a growing knowledge of the dynamic, predictable nature of ocean currents. Engineering and transport were nevertheless still dependent on power derived from wind or water, or harnessing animals – or humans.

The first energy transition that soon revolutionized engineering, industry and transport was stimulated – ironically – by Thomas Newcomen's invention of steam engines by Newcomen dewatering coal mines in England. Coal is an energy-rich alternative for heating and it was needed to supplement the depletion of forest resources – as a result of land clearance for agriculture, for furnaces in iron production, housing and shipbuilding.

It is fascinating to consider that the biological and Earth sciences both emerged within this highly mechanistic context. Remarkable observations and deductive insights by pioneer geologists James Hutton, Charles Lyell and Louis Agassiz provided astonishing and controversial evidence for an incredibly long and complex Earth history. They also revealed the occurrence of drastic

and catastrophic changes in the past, although the significance of the paleontological record and the biostratigraphical subdivision of geological time was not initially understood in terms of evolutionary theory and catastrophic mass extinction events.

These insights into the depth of Earth history provided a stimulus for the celebrated maritime voyage of the HMS Beagle, through which Charles Darwin initiated yet another revolution in understanding the Earth. Through the meticulous observations and collections which he made during this epic voyage he, and Alfred Wallace in South-East Asia, came to appreciate that the living world is not static, but represents an intricate web of interactions and interdependence, laying the foundation for studies of species evolution and dynamically changing ecosystems. The Voyage of the Beagle – still less than 200 years ago – was also significant in the development of the predictive capability of meteorology, through the insights of Captain Robert Fitzroy into coupling between atmospheric and oceanic geodynamics. However, to these scientists, the potential for human activity to influence these global scale processes within less than 200 years could scarcely have seemed credible.

By the close of the 19th century, further revolutions in harnessing energy transformed industrial society, with generation of electricity – from water and coal – and the exploitation of oil for transport. A hundred years ago then, planet Earth was – probably for the first time – inhabited by a species with the capacity to consciously evaluate and understand – as well as exploit – its own ecological regime. However, with rare exceptions, there was little awareness that human activity could interact with and influence global systems. These issues emerged progressively from the mid-20th century – the precursor to the European Union was founded essentially to ensure that resources security in the form of coal and iron would

no longer lead to global conflict, air pollution controls restricted coal-burning were successfully enacted in the United Kingdom.

In 1962 the publication of Rachel Carson's *Silent Spring* (*Äänetön kevät*) drew alarming attention to the ecological impact of global dispersion of industrial agricultural chemicals, while Flannery (1994) examined the effect of habitat destruction and species loss during human occupation of landscapes in his book "The Future Eaters". Amidst this, an appreciation of the complex interactions in global systems and the implications of the finite nature of earth resources for a growing human population were analyzed in the report "The Limits to Growth" (Meadows et al. 1972) – a pioneer in complex systems modelling and the subject of much admiration and much criticism!

By the middle 1980's sufficient global data from ocean and atmospheric studies revealed changes in atmospheric composition that could be attributed to human industrial activity – notably chlorofluorocarbons that had rapidly contributed to upper atmospheric ozone depletion, and gaseous oxides of carbon, nitrogen, and sulfur. The contribution of agriculture and forest clearance has also documented over pre-industrial time as well as the current. Ruddiman (2005) discerned subtle methane increases coincident with the adoption of rice-farming in Asia, while in Finland, as elsewhere, intense debate currently continues over the capacity of forest and grassland ecosystems to sequester carbon and buffer changes in atmospheric greenhouse gases.

The Gaia hypothesis as a potential approach to analyzing and responding to the global crisis

The inspiration for the Gaia hypothesis formulated by James Lovelock (1979) derived from an appreciation of the special quality of Earth, viewed from an astrophysical

perspective. The hypothesis was formalized and popularized rapidly, partly no doubt due to its alignment with growing global environmental awareness.

If the Gaia hypothesis is a valid construct for explaining life on Earth and the dynamic balances and changes in ecosystems, does it also follow that Gaia would have sensory capabilities and initiate responses to changes in the environment, be they geological, oceanic, or atmospheric, or even extra-terrestrial in origin? Is it conceivable that humans represent the evolution of such sensory capabilities within Gaia?

In a prescient yet somewhat whimsical paper, Hsü (1992) reviewed Earth history from the perspective of the Gaian hypothesis. Hsü suggested that Gaia was charting a steady course vacillating between potentially devastating Icehouse and Greenhouse end states. Evolutionary biological advances led to, at various times, conditions threatening to destabilize the system – for example colonization of land by plants and runaway generation of CO₂, which was curbed by the supercontinent Gondwana's ice ages, and burial of organic matter to form coal, gas, and petroleum resources in sedimentary basins. Hsü concluded with rather flippant speculation that Gaia has fostered humans to release this carbon, to ensure that the current ice age regime might be terminated through human industrial intervention, thus averting the still more dire outcome of a permanent Icehouse!

From such a Gaian perspective, it seems remarkable that the human species, at the precise moment that it threatens planetary stability, has also developed the capacity to observe and comprehend the impending resource crisis and its implications its own survival and, if we add a moral or altruistic dimension, that of other species. From a more objective scientific approach, this emergence of awareness and the capacity of conscious, directed intervention shares much in common with the fundamen-

tal changes in emergence in self-organized critical systems (Bak 1996). The Gaia hypothesis has another attractive feature in this time of misinformation and divisiveness, in that it is an ethically neutral construct and should allow respectful collaboration across the spectrum of worldviews, wherever life is respected.

If any of these ideas resonate, or better still, if anyone has ideas how to proceed further, engage and focus better, writer would really welcome feedback and ideas and asks to be contacted to given email addresses.

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The writer's ancestry can be traced to the late Devonian placoderm fishes of eastern Australia and his career has evolved from paleontology through to developing and applying mineral systems mapping and modelling to metallic and energy minerals, particularly in Australia and Fennoscandia. A fascination with the beauty of Earth processes and landscapes and an ongoing concern over equitable and ecologically responsible management of earth resources continue to motivate both research and spare time.

Tiivistelmä

Muuttuva ilmasto ja ihmiset

Gaia-hypoteesin näkökulmasta

Ihmiskunta kohtaa (ja aiheuttaa!) monia ympäristökriisejä eri mittakaavoissa – mikrobien nanotasolta globaaleihin valtamerivirtausten ja ilmakehän häiriöihin asti. Planeettamme kasvit saavat energiansa ja ravintonsa fotosynteesin avulla ja ovat eläneet siten jo miljoonia vuosia dynaamisessa tasapainossa. Nyt kuitenkin ihmisten pyrkimykset täyttää omat energia- ja ravintotarpeensa uhkaavat ympäristömme sietokykyä kestävämmällä tavalla.

Elämme tiettävästi ensimmäistä kertaa maapallon historiassa sellaista aikaa, jolloin joku eliölaji on aiheuttanut valtavia muutoksia ympäristöönsä ja samanaikaisesti kehittänyt

kyvyn havainnoida, arvioida ja jopa ennakoida sekä lievittää aikaansaamiensa muutosten vaikutuksia. Luonnontieteet, ja erityisesti geologian tuoma aikaperspektiivi, ovat olleet avainasemassa tässä tehtävässä jo viitisen vuosisataa. Tieteen merkitys tulee kasvamaan tulevina vuosikymmeninä, jotka ovat ratkaisevia pyrkimyksessä lievittää tai korjata näitä globaalisia uhkia ja löytää uusi tasapainotila.

Tässä yhteydessä on mielenkiintoista tuoda esille James Lovelockin Gaia-hypoteesi (Lovelock 1979). Gaia on kiehtova, oivallinen ja hyödyllinen käsite: se esittää maapallon aktiivisesti säätelevän elämälle suotuisia olosuhteita. Geologian historia ja kehitysoppi osoittavat, että maapallo on kohdannut monia katastrofaalisia muutoksia ja lukuisat lajit ovat kadonneet. Gaia on myös eettisesti ja moraalisesti neutraali käsite kun pohditaan ihmiskunnan eksistentiaalista merkitystä ja sisäisiä erimielisyyksiä. Herää kuitenkin kysymys, olemmeko ilmaantuneet Gaian evoluutiossa sellaisessa hetkessä, jotta voisimme varjella, viljellä, tutkia ja ohjata maapallon kehitystä sopusuunnassa muidenkin lajien kanssa – vai olemmeko astumassa varoituksista huolimatta sukupuuton polulle?

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