GLOBAL ECOLOGY

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Summary

Human activities have brought about an accelerating transformation of the global ecosystem. The deleterious effects of this global change necessitate research into the form and function of the global ecosystem to help vouchsafe a sustainable future for humanity. The global ecosystem (Earth system, Gaia) comprises life and life-supporting systems, its two chief components being the ecosphere (life, air, soil, and water) and the human sphere, which comprises the anthroposphere (homosphere, technosphere) and the mental sphere (noösphere). Fortuitously, as the need for investigating the global ecosystem became urgent, scientists invented new tools with which to do the job: aerial photography and remote sensing, computer simulation, and the building of artificial biospheres. In addition, methods of reconstructing past changes in the global ecosystem improved greatly. Armed

with their new toolkits, global ecologists now map, measure, and monitor the current state of the global ecosystem; piece together its state in the recent and distant past; create virtual ecosystems on computers to predict future changes and to postdict past changes; and build large and small artificial biospheres to mimic conditions in the real biosphere. The information garnered from the measuring, modelling, and miniaturizing endeavours partly informs the philosophy and practice of sustainable management of local, regional, and global ecosystems.

1. Introduction

a. The Need for Global Ecology

Global ecology is the science of the Earth ecosystem. Its object of study is the entirety of life (animals, plants, microbes) and life-support systems (air, water, and soil) on the Earth, variously referred to as the biosphere, the ecosphere, the global ecosystem, Gaia, and the Earth system. This global ecosystem is robust, but far from stable, kept as it is in a state far removed from thermodynamic equilibrium by living things.

The global ecosystem is the ever-changing product of interacting biological, physical, and chemical processes. Organisms of different kinds photosynthesize, respire, eat, produce wastes, dig, burrow, and build nests and mounds. Their actions are individual, but processes in the atmosphere, sediments, waters, and landscapes integrate the effects of their actions. Life depends upon its interacting with the non-living world. All organisms must win essential nutrients from their environment at sufficient rates and concentrations, and they must rid themselves of waste products. The supply and removal of materials in the biosphere are primarily the result of biological activity, with suppliers and removers often being different groups of organisms. Processes in the cosmic environment and the geological environment influence the rich web of interactions in the global ecosystem. Volcanoes, drifting plates, mountain building, and many other geological processes affect life and life-support systems. Solar emissions, solar cycles, lunar cycles, planetary cycles, cosmic debris, and other astronomical processes also affect life and life-support systems. Last but no longer least, humans deeply influence processes in the global ecosystem, of which they are a part. Indeed, a spur to the recent growth of global ecology is the worrying impact of the human species on the biological and physical worlds. Humans, like all organisms, interact with their environment. Unlike other species, they have acquired the ability to alter the environment in novel ways, putting land under crops, building towns and cities, extracting minerals and fuels, and constructing factories. The exponential growth of the human population, coupled with advances in agricultural and industrial technology and transport and the lust of western civilization to occupy new lands, led to a dramatic change in the land-cover of the planet, which started around the late seventeenth century. This truly global change, known as the Great Transformation, has continued at a quickening.

Human action has transformed between one-third and one-half of the land surface. Since the beginning of the Industrial Revolution, the concentration of carbon dioxide in the atmosphere has increased by nearly 30%. Humanity fixes more atmospheric nitrogen than is fixed by all natural nitrogen-fixing processes. Humans use more than one half of all accessible surface fresh water. Human-induced habitat destruction, habitat fragmentation, and the introduction of exotic species have driven around a quarter of the bird species on

Earth to extinction. Humans affect global biogeochemical cycles, including the carbon, nitrogen, and sulphur cycles; they mobilize such metals as arsenic and mercury; they alter the water cycle; and they reduce biodiversity. They have caused accelerated erosion of soils in many parts of the world; and they have nearly exhausted some non-renewable resources and placed some renewable resources in jeopardy. So systematic is the global change wrought by the human species that some writers judge it appropriate to designate the last two hundred years as a new geological epoch—the Anthropocene. And that epoch has only just begun. The latest prediction by the Intergovernmental Panel of Climate Change (IPCC) is for a 1.4 to 5.8 ^{o}C average increase in global surface temperature over the period 1990 to 2100. Such changes will have profound effects on the global ecosystem and a new global science has emerged to study them—global ecology and Earth system science. Global ecologists and Earth system scientists both study the planet as a single, complex, and dynamic entity comprising the geosphere and biosphere, although their foci are slightly different.

Global ecology as a subject has grown from the increasingly pressing need over the last few decades to understand the interconnections between life and life-supporting systems and how global change affects them. The science of global ecology is a response to these problems and aims to investigate the past, present, and future consequences of human activities. It seeks to explain how humans and other living things interact with their physical and chemical surroundings. It looks at the Earth as a single system with global dimensions. An approach with such a broad compass is necessarily multidisciplinary, integrative, and dauntingly challenging.

Earth system science is a popular, fast-growing, and well-funded discipline, as the large number of acronyms associated with it suggests. In its modern guise, it started with the International Geosphere–Biosphere Programme (IGBP), which the International Council of Scientific Unions (ICSU) established in 1986. Its real roots run back through the writings of Vladimir I. Vernadsky to nineteenth century physical geography. It tackles global storages and flows of energy and biogeochemicals, employing remote-sensing and Geographical Information System (GIS) technology alongside computer modeling. In doing so, its focus is global change and its regional, and to a lesser degree local, consequences. Some Earth system scientists also consider management issues.

b. What is the Global Ecosystem?

The global ecosystem goes by at least three names: the Earth system, the ecosphere, and Gaia. Each of these has a slightly different meaning, though they are all similar ideas.

1.2.1 The Earth System

The Earth system, G, may be defined as the ecosphere, E, and the human sphere, H:
Earth system = (Ecosphere, Human sphere)

$G = (E, H)$

The ecosphere, E, is composed of several spheres—the atmosphere (air), the biosphere (life), the hydrosphere (liquid water) and cryosphere (frozen water), the pedosphere (soil), and the toposphere (topography). Each of these spheres stores materials and energy, transforms them, and exchanges them with other spheres. The interactions integrate to form natural ecosystems. The human sphere has two components: a physical component—the anthroposphere or homosphere or technosphere, *A*; and a metaphysical component—the mental sphere, *M*. So, written symbolically:

$G = (E; A, M)$

The anthroposphere is the totality of human presence, actions, and physical creations in the landscape—farms, towns, cities, roads, railways, and all manner of human-made artefacts. It is a dynamic system, which, like the systems in the ecosphere, involves the input, storage, transport, transformation, and output of materials and energy. The anthroposphere metabolizes materials. The imported, stored, and exported materials involved in the metabolism of the anthroposphere are now closely studied. Many studies consider regional economies (see Figure 1), but others look at the global picture. Key subsystems in the regional economy include agriculture, domestic households, industry, and waste management. So widespread is the human impact that very few areas of strictly natural ecosystems remain. Most ecosystems now display varying degrees of human influence. Semi-natural ecosystems are the least altered. Some woodlands, forests, and grasslands, for example, come under this heading, as do traditional, solar-powered, low-input, organic farming ecosystems. Agro-industrial ecosystems and suburban and urban ecosystems, which are powered by fossil fuel and nuclear energy, are human-made ecosystems. In contrast to natural and semi-natural ecosystems, they tend not be self-organizing and lack regenerative capacities. The result is that they produce much waste and pollution that impacts widely upon on the surviving natural and semi-natural ecosystems and upon human health.

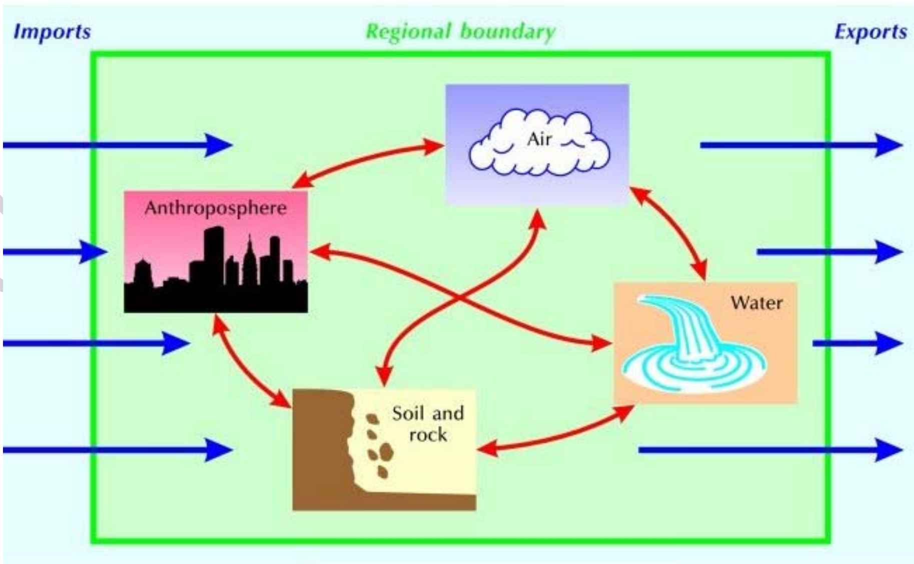

Figure 1. Regional flows

The mental sphere is a less tangible idea. It originated in Vernadsky's noösphere, the 'sphere of the mind', but is taken here to mean 'the sphere of human consciousness and mental activity', following the definition given by Pierre Teilhard de Chardin. Hans-Joachim Schellnhuber dubs it the 'global subject', which is 'a self-organized cooperative phenomenon, a self-conscious force driving global change either to a sustainable trajectory or to self-extinction' (Schellnhuber 2001, 25). In other words, it is the emerging highly-structured global society, presently consisting of personal networks, pressure groups, non-governmental organizations, academic communities, and global corporations, and so on, that decides the blueprint for managing planet Earth. The growth of worldwide transport and telecommunications systems made its materialization possible. Sanguine commentators with utopian proclivities believe that it may evolve into a truly global society in which all individuals are so interdependent that they grow and evolve with a common purpose.

1.2.2. Gaia

Gaia is the Greek goddess of the Earth, daughter of Chaos, mother and lover of the sky (Uranus), the mountains (Ourea), and the sea (Pontus). It is the name applied to the global ecosystem in the Gaia hypothesis. As first propounded by James Lovelock and Lynn Margulis, the Gaia hypothesis asserts that, shortly after it first appeared, life has stood at the helm of the ecosphere, exercising near total homeostatic control over the terrestrial environment (see *Biosphere Evolution*).

At least two versions of the Gaia hypothesis exist—weak Gaia and strong Gaia. Weak Gaia is the contention that life wields a substantial influence over some features of the non-living world. It does so mainly through playing a pivotal role in biogeochemical cycles. Its influence is sufficient to have produced highly anomalous environmental conditions in comparison with the flanking terrestrial planets, Venus and Mars. Notable anomalies include the presence of highly reactive gases (including oxygen, hydrogen, and methane) coexisting for long times in the atmosphere, the stability of the Earth's temperature in the face of increasing solar luminosity (brightness of the Sun), and the relative alkalinity of the oceans. Life's interacting with the surface materials of the planet has produced these unusual conditions of temperature, chemical composition, and alkalinity, which have persisted over much of geological time. For this reason, the global ecosystem demands an understanding of the world's biota and its properties. The weak Gaia hypothesis does not call upon anything other than mechanistic processes to explain terrestrial evolution, but it does argue that the biosphere largely built, and maintains, the non-living portion of the Earth system.

Strong Gaia is the unashamedly teleological idea that the Earth is a superorganism controlling the terrestrial environment to suit its own ends. Lovelock seems to favour strong Gaia, believing that it is useful to regard the planet Earth, not as an inanimate globe of rock, liquid, and gas, driven by geological processes, but as a single life-form, a living planetary body that adjusts and regulates the conditions in its surroundings to maintain conditions suitable for life. For Lovelock, Gaia includes the biosphere and the rest of the Earth. He explains that the rocks, the air, and the oceans are as much a part of Gaia as a snail's shell is a part of a snail. It is uncertain if life is able to exert an influence deep inside the Earth, or if the biosphere is merely the epidermis of a living global creature. However, the evolving biosphere has maintained an intercourse with the Earth's interior through plate-tectonic processes, the convective system in the mobile parts of the mantle being the medium and the mechanism of communication.

Gaian scientists claim that traditional biology and geology offer ineffective methods with which to study the planetary organism. The right tool for the job, they contend, is geophysiology—the science of bodily process writ large and applied to the entire planet, or at least that outer shell encompassing the biosphere. However, the differences of approach and emphasis between weak and strong version of Gaia are fundamental—if the strong Gaia hypothesis should be correct, and the Earth really is an integrated superorganism, then the biosphere will regulate and maintain itself through a complex system of homeostatic mechanisms, just as a human body adjusts to the vicissitudes of its surroundings. Accordingly, the biosphere may be a far more robust and resilient beast than has often been suggested. For instance, homeostatic mechanisms may exist for healing the hole in the ozone layer or preventing the global thermometer from blowing its top.

1.3. The Tools of Global Ecology

The investigation of the global ecosystem demands new instruments. Particularly useful are three techniques for gaining insights on a global scale: Earth reconnaissance from space, computer simulation models, and the building of artificial biospheres. These techniques are macroscopic and, unlike microscopic techniques that magnify detail, step back to give a holistic view of the planet. Schellnhuber has dubbed them the 'bird's eye' principle, the digital-mimicry principle, and the 'Lilliput' principle. It was perhaps fortuitous that, at around the same time as modern global ecology emerged as a subject, these tools for examining the global ecosystem as a whole were newly available. First, satellites provided platforms for cameras that could take remotely sensed images of the entire planetary surface, and the data-storage capacity and speed of computers enabled the development of suitable GIS software for information storage, manipulation, and retrieval. Second, it was possible, partly owing to the power of computers, to run sophisticated modelling programmes to simulate climatic and other global changes at a high level of spatial resolution. Third, some researchers had the idea of designing and building an artificial biosphere in the Sonora Desert, some forty miles north of Tucson, Arizona. Biosphere-II is a self-contained structure that, its builders hoped, would mimic the workings the actual biosphere—Biosphere-I. Other scientists have embarked on similar but smaller-scale ventures.

Coupled with these new tools for studying the global ecosystem are advances in methods for probing the global ecosystem in the past. Understanding the nature of past states of the global ecosystem is a vital complement to understanding its current state. Reconstructing global change in the historical and geological past provides an empirical yardstick with which to test the causes and effects of environmental changes in the present. In addition, past changes are crucial to understanding future changes. Thus, an understanding of the medium- and long-term evolution of the global ecosystem is a key tool in global ecology. The next sections consider the mapping and measuring, the modelling, the miniaturization, and the management of the global ecosystem.

2. Mapping and Measuring the Global Ecosystem

As a starting point to understanding the nature and complexities of the ecosphere and the human sphere, it is helpful to firstly map and measure them. A picture of the natural and human worlds began to emerge from explorations by the western European nations who sought out new lands and new resources. In the wake of this quest, the framework for a global system of observation stations emerged providing an important basis for understanding the world today. The historical goal of global inventorying has continued through the application of a range of technologies associated with engineering, telecommunications, and the computer, to a point where much of the land surface is now mapped and categorized. These new technologies, including those associated with aerial photography, remote sensing, and Global Positioning Systems (GPSs), greatly improve the potential to continuously, or near continuously, monitor the global ecosystem. In conjunction with computer-based interpretation and management tools, such as image processing and GIS, these new-fangled technologies have extended the ability to integrate disparate datasets and re-create aspects of the world virtually. Such models shed further light on a wide range of patterns and processes, such as those associated with past and present human–environment interactions, and open up the opportunity to assess the potential impacts of human actions and activities and create a more sustainable future.

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Biographical Sketch

Richard Huggett is a Reader in Geography at the University of Manchester. He has BSc and PhD degrees from University College London. His current research interests focus on four big questions: How does the environment form and function? How does the environment change? How fast does the environment change? How do ecology and evolution interact? His recent books include *Environmental Change: The Evolving Ecosphere* (1997), *Catastrophism: Asteroids, Comets, and Other Dynamic Events in Earth History* (1997), *Fundamentals of Biogeography* (1998), *Topography and the Environment* (with J. E. Cheesman) (2002), and *Fundamentals of Geomorphology* (2003).