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Ecosystems

1.6

Erle C. Ellis

An ecosystem is a community of organisms interacting with each other and with their abiotic environment such that energy is exchanged and system-level processes, such as the one-way flow of energy and the cycling of elements, emerge.

The ecosystem is a core concept in the fields of biology and ecology, serving as the level of biological organization in which organisms interact simultaneously with each other and with their immediate environment. As such, ecosystems are a level above that of the ecological community (organisms of different species interacting with each other) but are at a level below, or equal to, biomes and the biosphere. Essentially, biomes are regional ecosystems, and the biosphere is the largest of all possible ecosystems.

Ecosystems include living organisms, the dead organic matter produced by them, the abiotic environment within which the organisms live and exchange elements (soils, water, atmosphere), and the interactions among these components. Ecosystems embody the concept that living organisms continually interact with each other and with the environment to produce complex systems with emergent properties, such that "the whole is greater than the sum of its parts" and "everything is connected".

The spatial boundaries, component organisms and the matter and energy content and flux within ecosystems may be defined and measured. However, unlike organisms or energy, ecosystems are inherently conceptual, in that different observers may legitimately define their boundaries and components differently. For example, a single patch of trees together with the soil, organisms and atmosphere interacting with them may define a forest ecosystem, yet the entirety of all organisms, their environment, and their interactions across an entire forested region in the Amazon might also be defined as a single forest ecosystem. Moreover, the interacting system of organisms that live within the guts of most animals may also be seen as an ecosystem (the "microbiome"), despite their

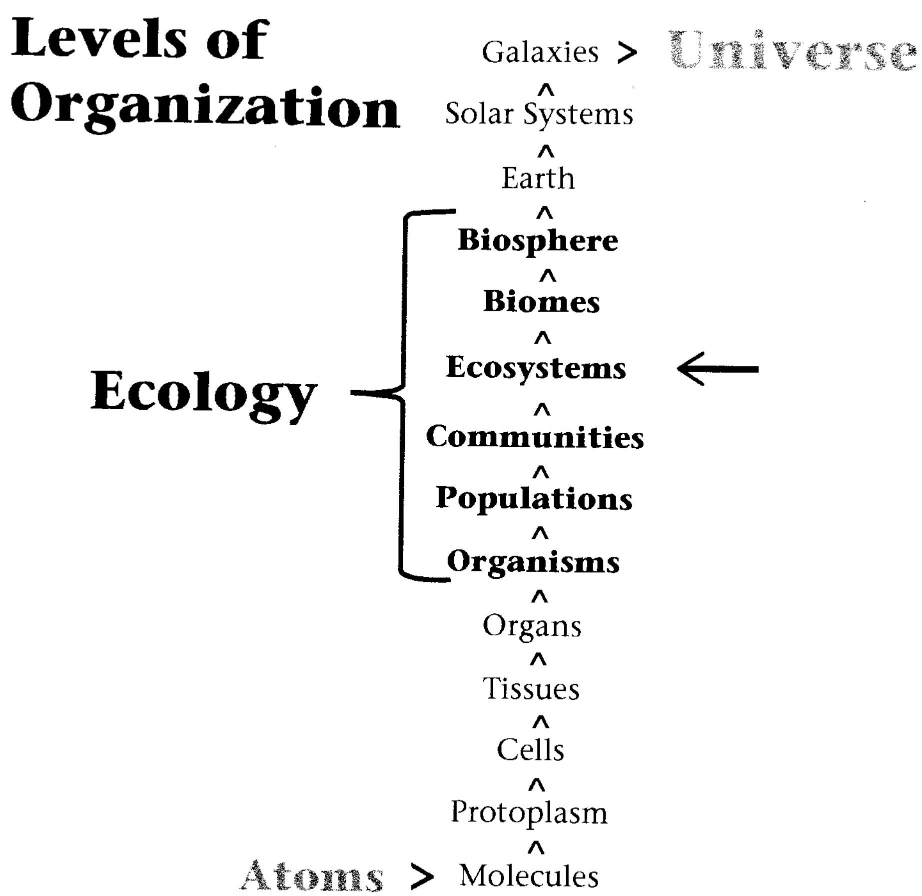

Figure 1.6.1 Levels of organization in ecology, highlighting ecosystems.

Credit: Erle Ellis.

residence within a single organism, seemingly violating the level of organization-defining ecosystems. Note also that interactions among ecosystem components are as much a part of the definition of ecosystems as their constituent organisms, matter and energy. Despite the apparent contradictions that result from the flexibility of the ecosystem concept, it is just this flexibility that has made it such a useful and enduring concept.

History of the ecosystem concept

The term "ecosystem" was first coined by Roy Clapham in 1930, but it was ecologist Arthur Tansley who fully defined the ecosystem concept. In a classic article in 1935, Tansley defined ecosystems as "The whole system, . . . including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment". The ecosystem concept marked a critical advance in the science of ecology, as Tansley specifically used the term to replace the "superorganism"

concept, which implied that communities of organisms formed something akin to a higher-level, more complex organism—a mistaken conception that formed a theoretical barrier to scientific research in ecology. Though Tansley and other ecologists also used the ecosystem concept in conjunction with the now defunct concept of the ecological "climax" (a "final", or "equilibrium" type of community or ecosystem arising under specific environmental conditions—as a "balance of nature"), the concept of ecosystem dynamics—the "fluxes of nature" has now replaced this. Eugene Odum, a major figure in advancing the science of ecology, made the ecosystem concept the central role in his seminal textbook on ecology, defining ecosystems as: "Any unit that includes all of the organisms (i.e. the "community") in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity (biodiversity), and material cycles (i.e. exchange of materials between living and nonliving parts) within the system is an ecosystem."

Ecosystem structure and function

Ecosystem components (structure)

Ecosystems may be observed in many possible ways, so there is no one set of components that make up ecosystems. However, all ecosystems must include both biotic and abiotic components, their interactions, and some source of energy. The simplest (and least representative) of ecosystems might therefore contain just a single living plant (biotic component) within a small terrarium exposed to light to which a water solution containing essential nutrients for plant growth has been added (abiotic environment). The other extreme would be the biosphere, which comprises the totality of Earth's organisms and their interactions with each other, abiotic, "spheres" of the Earth system (the Atmosphere, Hydrosphere, Lithosphere, etc.). And of course, most ecosystems fall somewhere in between these extremes of complexity.

At a basic functional level, ecosystems generally contain primary producers capable of harvesting energy from the Sun by photosynthesis and of using this energy to convert carbon dioxide and other inorganic chemicals into the organic building blocks of life. Consumers feed on this captured energy, and decomposers not only feed on this energy, but also break organic matter back into its inorganic constituents, which can be used again by producers. These interactions among producers and the organisms that consume and decompose them are called trophic interactions, and are composed of trophic levels in an energy pyramid, with most energy and mass in the primary producers at the base, and higher levels of feeding on top of this, starting with primary consumers feeding on primary producers, secondary consumers feeding on these, and so on. Trophic interactions are also described in more detailed form as a food chain, which organizes specific organisms by their trophic distance from primary producers, and by food webs, which detail the feeding interactions among all organisms in an ecosystem. Together, these processes of energy transfer and matter cycling are essential in shaping ecosystem structure and function and in defining the types of interactions between organisms and their environment. It must also be noted that most ecosystems contain a wide diversity of species, and that this diversity should be considered part of ecosystem structure.

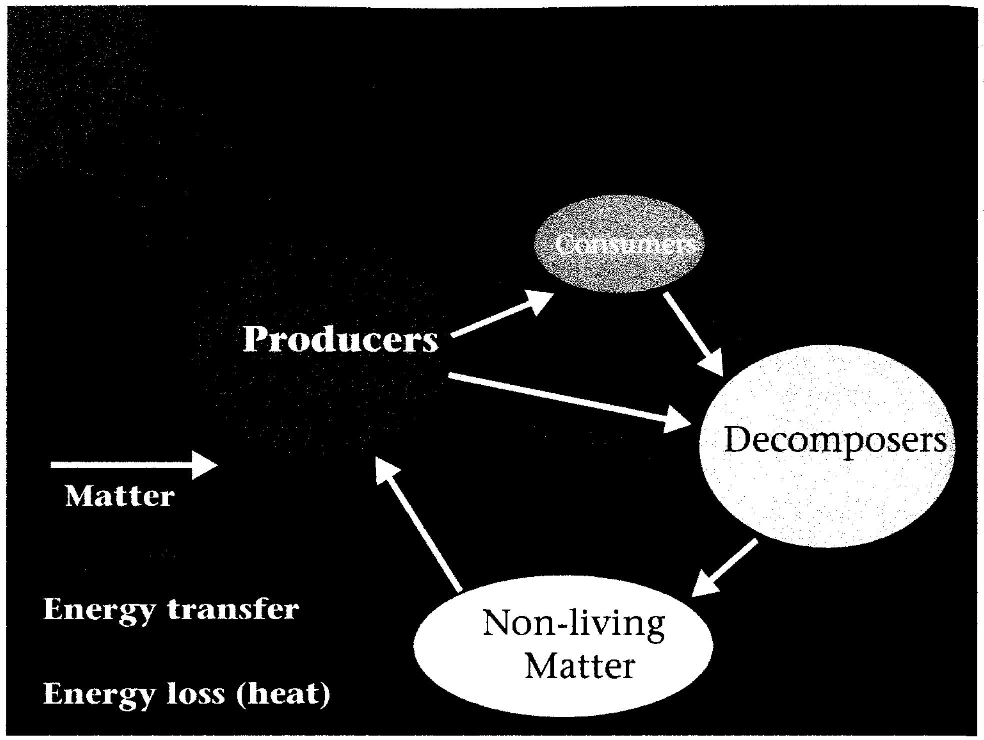

Figure 1.6.2 Illustration of the flow of matter and energy in ecosystems.

Credit: Erle Ellis.

Ecosystem processes (function)

By definition, ecosystems use energy and cycle matter, and these processes also define the basic ecosystem functions. Energetic processes in ecosystems are usually described in terms of trophic levels, which define the role of organisms based on their level of feeding relative to the original energy captured by primary producers. In keeping with thermodynamic laws, energy does not cycle, so ecosystems require a continuous flow of high-quality energy to maintain their structure and function. For this reason, all ecosystems are "open systems" requiring a net flow of energy to persist over time—without the Sun, the biosphere would soon run out of energy!

Energy input to ecosystems drives the flow of matter between organisms and the environment in a process known as biogeochemical cycling. The biosphere provides a good example of this, as it interacts with and exchanges matter with the lithosphere, hydrosphere and atmosphere, driving the global biogeochemical cycles of carbon, nitrogen, phosphorus, sulfur and other elements. Ecosystem processes are dynamic, undergoing strong seasonal and even daily cycles in response to changes in solar irradiation, causing fluctuations in primary productivity and varying the influx of energy from photosynthesis and the fixation of carbon dioxide into organic materials, driving remarkable annual variability in the carbon cycle—the largest of the

global biogeochemical cycles. Fixed organic carbon in plants then becomes food for consumers and decomposers, who degrade the carbon to forms with lower energy, and ultimately releasing the carbon fixed by photosynthesis back into carbon dioxide in the atmosphere, producing the global carbon cycle. The biogeochemical cycling of nitrogen also uses energy, as bacteria fix nitrogen gas from the atmosphere into reactive forms useful for living organisms using energy obtained from organic materials and ultimately from plants and the Sun. Ecosystems also cycle phosphorus, sulfur and other elements. As biogeochemical cycles are defined by the exchange of matter between organisms and their environment, they are classic examples of ecosystem-level processes.

Ecosystem research

Scientists who study entire ecosystems are generally called systems ecologists. However, most ecologists use the ecosystem concept and make measurements on ecosystem properties even if their work focuses on a single species or population.

Observing ecosystems

Researchers can make direct observations on ecosystems in the field and indirect observations using remote sensing. Direct measurements include sampling and measurement of soils and vegetation, characterization of community structure and biodiversity, and the use of instruments for observing gas exchange and the fluxes of nutrients and water. As ecosystems can be very challenging to recreate under laboratory conditions, observational studies on existing ecosystems are a core methodology of ecosystem science.

Ecosystem experiments

Though it has historically been difficult, ecosystems are now often studied using the classic experimental methods of science. For example, small- and meso-scale ecosystems containing a significant set of interacting organisms and their environment may be created in the laboratory, or in enclosures in the field. There are also methods for excluding organisms or altering environmental conditions in the field, such as the addition of nutrients and artificially enhancing carbon dioxide concentrations, temperature or moisture.

Modeling

To better understand how ecosystems function and change, modeling is often used to simulate ecosystem dynamics, including the biogeochemical cycles of carbon and other elements, the role of specific species or functional groups in controlling ecosystem function, and even dynamic changes in ecosystem structure and function across landscapes and the entire biosphere.

The future

Ecosystem science is evolving rapidly in both methodology and focus. Human alteration of ecosystems is now so pervasive globally that ecologists are working to integrate humans into ecosystem science at many levels—including the study of urban ecology, agroecology, social-ecological systems and global ecology and international efforts to assess the state of ecosystems globally—such as the "Millennium Ecosystem Assessment" and the Intergovernmental Panel on Biodiversity and Ecosystem Services. New techniques for ecosystem modeling are being developed all the time, as are new methods for observing ecosystems from space by remote sensing and aerial platforms, and even by networks of sensors embedded in soils and plants across ecosystems and on towers that can make observations on ecosystem exchanges with the atmosphere on a continuous basis. Examples of cutting edge ecosystem research are the Carnegie Airborne Observatory—an aerial remote sensing system capable of precisely mapping ecosystem carbon and species diversity, and the development of the National Ecological Observatory Network (NEON), a continental-scale research platform for discovering and understanding the impacts of climate change, land-use change, and invasive species on ecosystems.

Learning resources

The Ecological Society of America http://www.esa.org/esa/
The National Ecological Observatory Network (NEON) http://www.neonscience.org/
The Millennium Ecosystem Assessment http://www.millenniumassessment.org/en/index.html
Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) http://www.ipbes.net/

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1.7

Environmental catastrophe

Giovanni Bettini

The destructive powers and vagaries of 'nature' have constantly reminded humans of the contingency of their lifeworld. Thunders and plagues descending from the sky. Waves surging from the seas. Tremors, smoke and magma surfacing from the earth's deepest strata. Such cataclysms are recurring traumas in human history, inscribed in myth, religion, and politics (Clark, 2011; Ghosh, 2016; Hulme, 2009). But today 'environmental catastrophe' means also something else, as it alludes more to post-apocalyptic Mad Max-like scenarios than to biblical plagues. It casts a dystopic vista over the possibility, detected with the tools of modern science, of a human-induced planetary collapse. This is the case for all the catastrophes environmentalists have warned about and mobilized against (such as mass species extinction, nuclear contamination, the ozone hole, desertification, and more recently climate change). The fact that humans themselves are causing the very problem opens up an ethical dimension to the catastrophe, and poses divisive questions: Who exactly is to blame – can we really talk about humanity as a whole? And who should do (have done) what to avoid the materialization of the catastrophe, or at least to mitigate its fallout?

This chapter looks closer at how the idea of catastrophe has been inscribed in modern and contemporary discourses on the environment. It also introduces contrasting views on whether the invocation of environmental catastrophe can foster awareness and mobilize action, or obfuscates the underlying issues.