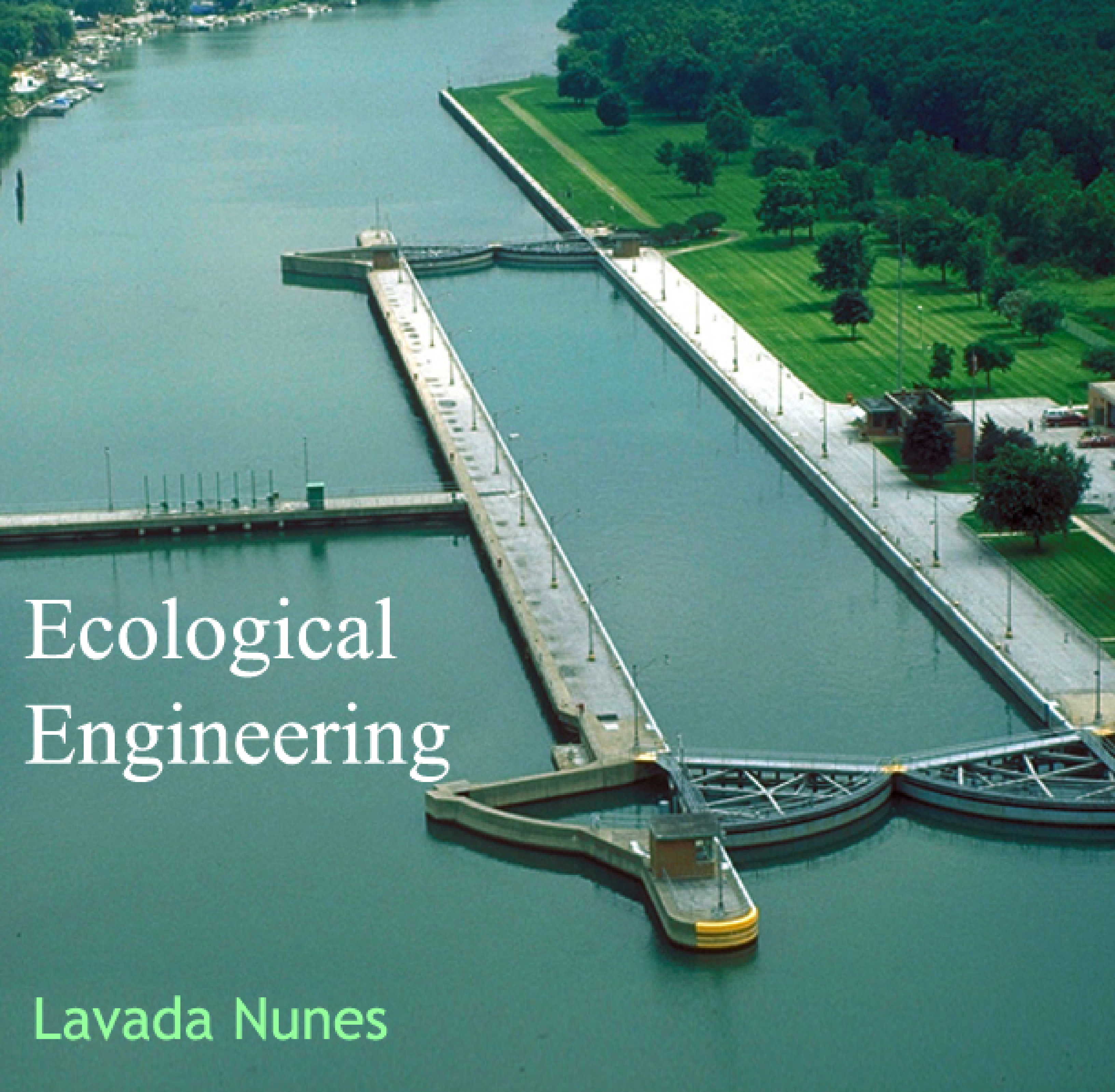
Ecological
Engineering
Lavada Nunes

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Introduction

Ecological engineering is an emerging study of integrating ecology and engineering, concerned with the design, monitoring and construction of ecosystems. According to Mitsch (1996) "the design of sustainable ecosystems intends to integrate human society with its natural environment for the benefit of both".

Overview

Ecological engineering emerged as a new idea in the early 1960s, but its definition has taken several decades to refine, its implementation is still undergoing adjustment, and its broader recognition as a new paradigm is relatively recent. Ecological engineering was introduced by Howard Odum and others as utilizing natural energy sources as the predominant input to manipulate and control environmental systems.

Mitsch and Jorgensen wrote that ecological engineering is designing societal services such that they benefit society and nature, and later noted the design should be systems based, sustainable, and integrate society with its natural environment. Odum emphasized that self-organizational properties were a central feature to ecological engineering.

Mitsch and Jørgensen were the first to define ecological engineering and provide ecological engineering principles. Later they refined the definition and increased the number of principles. They defined and characterized ecological engineering in a 1989 book and clarified it further in their 2004 book. They suggest the goal of ecological engineering is: a) the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution or land disturbance, and b) the development of new sustainable ecosystems that have both human and ecological values. They summarized the five concepts key to ecological engineering as:

1. it is based on the self-designing capacity of ecosystems,
2. it can be a field test of ecological theory,
3. it relies on integrated system approaches,

4. it conserves non-renewable energy, and
5. it supports biological conservation.

Bergen et al. defined ecological engineering as:

- utilizing ecological science and theory,
- applying to all types of ecosystems,
- adapting engineering design methods, and
- acknowledging a guiding value system.

Barrett (1999) offers a more literal definition of the term: "the design, construction, operation and management (that is, engineering) of landscape/aquatic structures and associated plant and animal communities (that is, ecosystems) to benefit humanity and, often, nature." Barrett continues: "other terms with equivalent or similar meanings include ecotechnology and two terms most often used in the erosion control field: soil bioengineering and biotechnical engineering. However, ecoengineering should not be confused with 'biotechnology' when describing genetic engineering at the cellular level, or 'bioengineering' meaning construction of artificial body parts."

This engineering discipline combines basic and applied science from engineering, ecology, economics, and natural sciences for the restoration and construction of aquatic and terrestrial ecosystems. The field of ecological engineering is increasing in breadth and depth as more opportunities to design and use ecosystems as interfaces between technology and environment are explored.

Examples

Implementation of ecological engineering has focused on the creation or restoration of ecosystems, from degraded wetlands to multi-celled tubs and greenhouses that integrate microbial, fish, and plant services to process human wastewater into products such as fertilizers, flowers, and drinking water.

Potential applications of ecological engineering in cities have included the field of landscape architecture, urban planning, and urban horticulture, which can be synthesized into urban stormwater management. Potential applications of ecological engineering in rural landscapes have included wetland treatment and community reforestation through traditional ecological knowledge.

Recent lifestyle and habitat planning examples include the permaculture movement.

Design guidelines

Ecological engineering design will follow a cycle similar to engineering design - problem formulation (goal), problem analysis (constraints), alternative solutions search, decision among alternatives, and specification of a complete solution. Elements that distinguish ecological engineering design are elaborated by many authors, however a singular approach is still absent. Typically, the design goal involves protecting an at-risk ecosystem, restoring a degraded ecosystem, or creating a new sustainable ecosystem to satisfy needs of nature and society.

A temporal framework is provided by Matlock et al., stating the design solutions are considered in ecological time. In selecting between alternatives, the design should incorporate ecological economics in design evaluation and acknowledge a guiding value system which promotes biological conservation.

- applying to all types of ecosystems,
- adapting engineering design methods, and
- Design steps should be based on utilizing ecological science and theory,
- the self-designing capacity of ecosystems;
- accept the adaptive management theory of learning from mistakes as the design will field test ecological theory;
- utilize integrated system approaches; and
- conserve non-renewable energy.

Academic curriculum

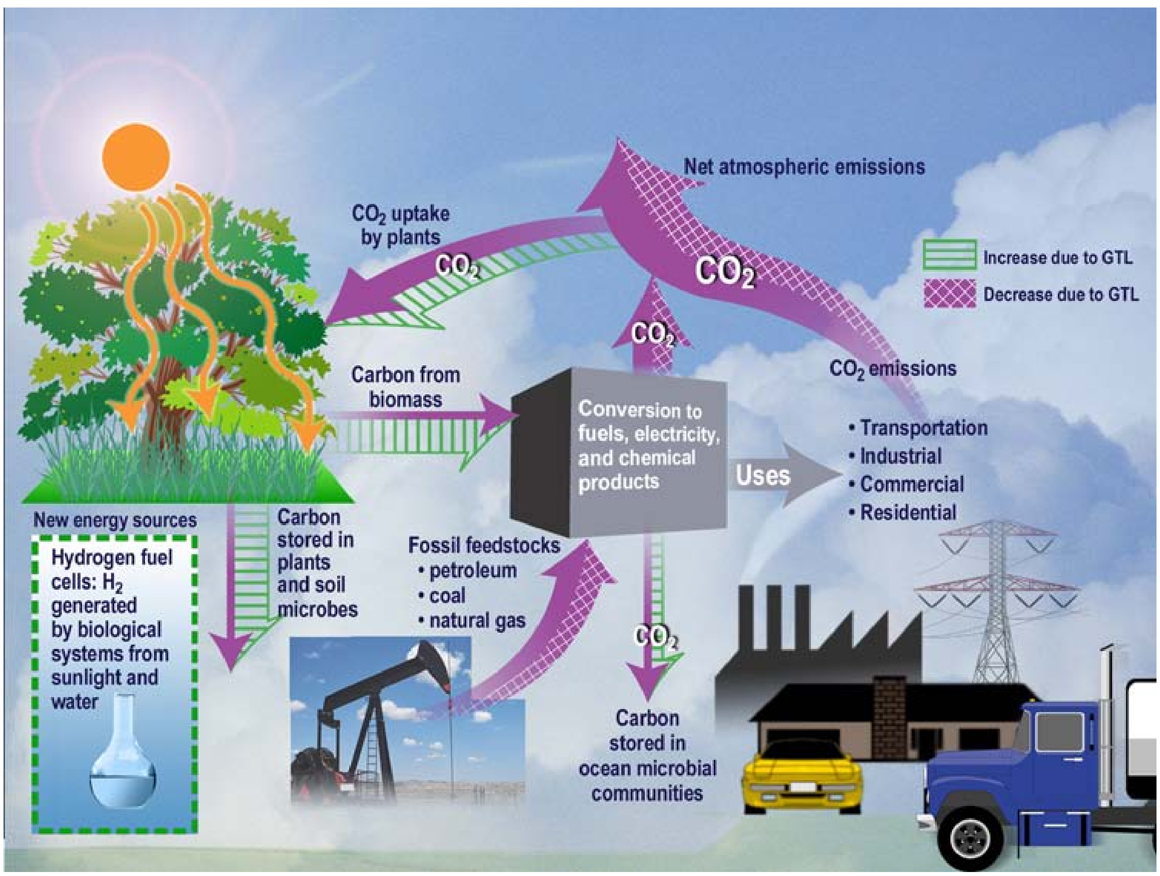
An academic curriculum has been proposed for ecological engineering, and key institutions across the US are indeed starting programs. Key elements of this curriculum are:

- quantitative ecology,
- systems ecology,
- restoration ecology,
- ecological modeling,
- ecological engineering,
- economics of ecological engineering, and
- technical electives.

Complementing this set of courses are prerequisites courses in physical, biological, and chemical subject areas, and integrated design experiences. According to Matlock et al., the design must identify constraints, characterize solutions in ecological time, and incorporate ecological economics in design evaluation. Economics of ecological engineering has been demonstrated using energy principles for a wetland., and using nutrient valuation for a dairy farm

Chapter 1

Systems Ecology



Ecological analysis of CO_2 in an ecosystem

Systems ecology is an interdisciplinary field of ecology, taking a holistic approach to the study of ecological systems, especially ecosystems. Systems ecology can be seen as an application of general systems theory to ecology. Central to the systems ecology approach is the idea that an ecosystem is a complex system exhibiting emergent properties. Systems ecology focuses on interactions and transactions within and between biological and ecological systems, and is especially concerned with the way the functioning of ecosystems can be influenced by human interventions. It uses and extends concepts from thermodynamics and develops other macroscopic descriptions of complex systems.

Overview

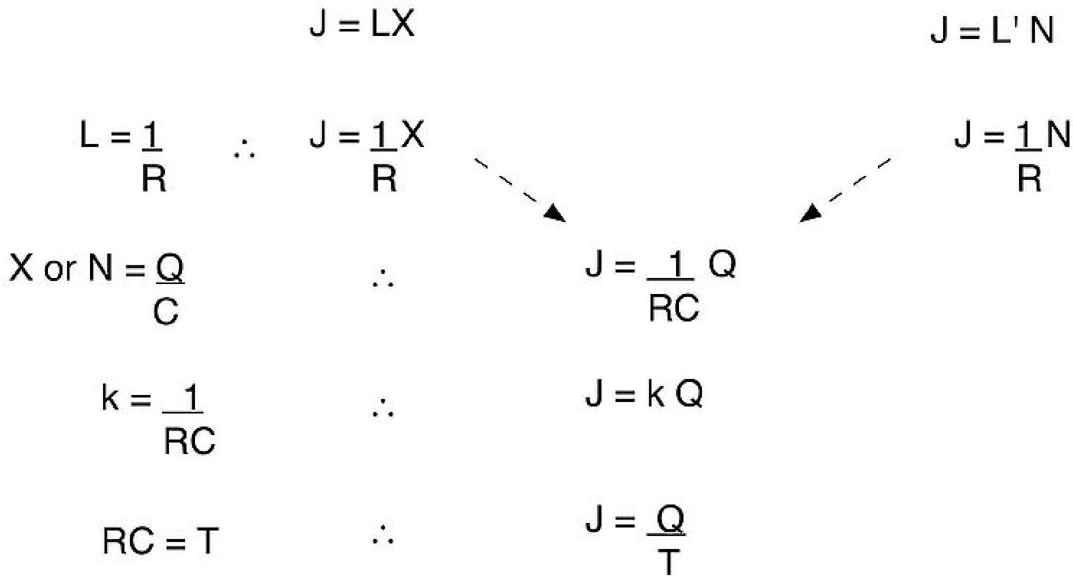
Systems ecology seeks a holistic view of the interactions and transactions within and between biological and ecological systems. Systems ecologists realise that the function of any ecosystem can be influenced by human economics in fundamental ways. They have therefore taken an additional transdisciplinary step by including economics in the consideration of ecological-economic systems. In the words of R.L. Kitching:

- *Systems ecology can be defined as the approach to the study of ecology of organisms using the techniques and philosophy of systems analysis: that is, the methods and tools developed, largely in engineering, for studying, characteriszing and making predictions about complex entities, that is, systems..*
- *In any study of an ecological system, an essential early procedure is to draw a diagram of the system of interest ... diagrams indicate the system's* ***boundaries*** *by a solid line. Within these boundaries, series of components are isolated which have been chosen to represent that portion of the world in which the systems analyst is interested ... If there are no connections across the systems' boundaries with the surrounding* ***systems environments****, the systems are described as* closed. *Ecological work, however, deals almost exclusively with* open *systems.*

As a mode of scientific enquiry, a central feature of Systems Ecology is the general application of the principles of energetics to all systems at any scale. Perhaps the most notable proponent of this view was Howard T. Odum - sometimes considered the father of ecosystems ecology. In this approach the principles of energetics constitute ecosystem principles. Reasoning by formal analogy from one system to another enables the Systems Ecologist to see principles functioning in an analogous manner across system-scale boundaries. H.T. Odum commonly used the Energy Systems Language as a tool for making systems diagrams and flow charts.

The fourth of these principles, the principle of maximum power efficiency, takes central place in the analysis and synthesis of ecological systems. The fourth principle suggests that the most evolutionarily advantageous system function occurs when the environmental load matches the internal resistance of the system. The further the environmental load is from matching the internal resistance, the further the system is away from its sustainable steady state. Therefore the systems ecologist engages in a task of resistance and impedance matching in ecological engineering, just as the electronic engineer would do.

Summary of relationships in systems ecology



summary of relationships

The image to the right is a summary of relationships between the storage quantity *Q*, the forces *X, N*, and the outflows *J*, resistance *R*, conductivity *L*, time constants *T*, and transfer coefficients *k* of ecosystem metabolism. The transfer coefficient "*k*", is also known as the *metabolic constant*.

Closely related fields

Deep Ecology

Deep Ecology is a school of philosophy pioneered by the Norwegian Philosopher, Gandhian scholar and environmental activist Arne Naess. Created in 1973 at an environmental conference in Budapest, it argues that the school of environmental management is anthropocentric, that the natural environment is not only "more complex than we imagine, it is more complex than we can imagine". Concerned with the development of an "ecological self", which views the human ego as a part of a living system, rather than apart from such systems, "Experiential Deep Ecology" of Joanna Macy, John Seed and others, seeks to transcend altruism with a deeper self-interest, based upon biospherical equality beyond human chauvinism.

Earth systems engineering and management

Earth systems engineering and management (ESEM) is a discipline used to analyze, design, engineer and manage complex environmental systems. It entails a wide range of subject areas including anthroplogy, engineering, environmental science, ethics and philosophy. At its core, ESEM looks to "rationally design and manage coupled human-natural systems in a highly integrated and ethical fashion"

Ecological economics

Ecological economics is a transdisciplinary field of academic research that addresses the dynamic and spatial interdependence between human economies and natural ecosystems. Ecological economics brings together and connects different disciplines, within the natural and social sciences but especially between these broad areas. As the name suggests, the field is made up of researchers with a background in economics and ecology. An important motivation for the emergence of ecological economics has been criticism on the assumptions and approaches of traditional (mainstream) environmental and resource economics.

Ecological energetics

Ecological energetics is the quantitative study of the flow of energy through ecological systems. It aims to uncover the principles which describe the propensity of such energy flows through the trophic, or 'energy availing' levels of ecological networks. In systems ecology the principles of ecosystem energy flows or "ecosystem laws" (i.e. principles of ecological energetics) are considered formally analogous to the principles of energetics.

Ecological humanities

Ecological humanities aims to bridge the divides between the sciences and the humanities, and between Western, Eastern and Indigenous ways of knowing nature. Like ecocentric political theory, the ecological humanities are characterised by a connectivity ontology and a commitment to two fundamental axioms relating to the need to submit to ecological laws and to see humanity as part of a larger living system.

Ecosystem ecology

A riparian forest in the White Mountains, New Hampshire (USA)

Ecosystem ecology is the integrated study of biotic and abiotic components of ecosystems and their interactions within an ecosystem framework. This science examines how ecosystems work and relates this to their components such as chemicals, bedrock, soil, plants, and animals. Ecosystem ecology examines physical and biological structure and examines how these ecosystem characteristics interact.

The relationship between systems ecology and ecosystem ecology is complex. Much of systems ecology can be considered a subset of ecosystem ecology. Ecosystem ecology also utilizes methods that have little to do with the holistic approach of systems ecology. However, systems ecology more actively considers external influences such as economics that usually fall outside the bounds of ecosystem ecology. Whereas ecosystem ecology can be defined as the scientific study of ecosystems, systems ecology is more of a particular approach to the study of ecological systems and phenomena that interact with these systems.

Industrial ecology

Industrial ecology is the study of industrial processes as linear (open loop) systems, in which resource and capital investments move through the system to become waste, to a closed loop system where wastes become inputs for new processes.

Chapter 2

Restoration Ecology

Recently constructed wetland regeneration in Australia, on a site previously used for agriculture

Restoration ecology is the scientific study and practice of renewing and restoring degraded, damaged, or destroyed ecosystems and habitats in the environment by active human intervention and action. Restoration ecology emerged as a separate field in ecology in the 1980s.

History

Land managers, laypeople, and stewards have been practicing restoration for many hundreds, if not thousands of years, yet the scientific field of "restoration ecology" was first identified and coined in the late 1980s by John Aber and William Jordan. The study of restoration ecology has only become a robust and independent scientific discipline over the last two decades, and the commercial applications are still in the process of developing.

Definition

The Society for Ecological Restoration defines ecological restoration as an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability". The practice of ecological restoration includes wide scope of projects including: erosion control, reforestation, the use of genetically local native species, removal of non-native species and weeds, revegetation of disturbed areas, daylighting streams, reintroduction of native species, as well as habitat and range improvement for targeted species. The term "ecological restoration" refers to the practice of the discipline of "restoration ecology".

The term restoration ecology is used for the academic study of the process, whereas "ecological restoration" is the term used for the actual project or process.

The process of ecological restoration is unique in land management perspectives, in that the goal is to restore the original or historic native ecosystem of a site, utilizing local native plant species, excluding exotic plants, and to restore the ecosystem to a self-sustainable state, within a certain amount of time.

In the view of biologist E. O. Wilson, "Here is the means to end the great extinction spasm. The next century will, I believe, be the era of restoration in ecology".

Restoration needs

There is consensus in the scientific community that the current environmental degradation and destruction of many of the Earth's biota is considerable, and is taking place on a "catastrophically short timescale". In fact, estimates of the current extinction rate are 1000 to 10,000 times the normal rate. For many people biological diversity (biodiversity) has an intrinsic value; humans have a responsibility toward other living things, and obligations to future generations.

On a more anthropocentric level, natural ecosystems provide human society with food, fuel and timber. More fundamentally, ecosystem services involve the purification of air and water, detoxification and decomposition of wastes, regulation of climate, regeneration of soil fertility, and pollination of crops. Such processes have been estimated to be worth trillions of dollars annually.

Habitat loss is the leading cause of both species extinctions and ecosystem service decline. There are two ways to reverse this trend of habitat loss: conservation of currently viable habitat and restoration of degraded habitats.

Conservation biology and restoration ecology

With regard to biodiversity preservation, it should be noted that restoration activities are complementary to, not a substitute for, conservation efforts. Many conservation programmes, however, are predicated on historical bio-physical conditions - i.e. they are incapable of responding to global climate change, and the assemblages "locked in" that become increasingly fragile and liable to catastrophic collapse. In this sense, restoration is essential to provide new spaces for migration of habitats and their associated flora and fauna. Also, conservation biology often has organisms, and not entire ecosystems and their functions, as its focus, and therefore has limited goals and aims.

Restoration ecology, as a scientific discipline, is theoretically rooted in conservation biology. While restoration ecology may be viewed as a sub-discipline of conservation biology, foundational differences exist between the disciplines' approaches, focuses and modes of inquiry.

Approaches

The fundamental difference between conservation biology and restoration ecology lies in their philosophical approaches to the same problem. Conservation biology attempts to preserve and maintain existing habitat and biodiversity. In contrast, restoration ecology assumes that environmental degradation and population declines are somewhat reversible processes. Therefore, targeted human intervention can lead to habitat and biodiversity recovery and eventual gains. This does not provide, however, an excuse for converting extremely valuable "pristine" habitat into other uses.

Focuses

First, both conservation biology and restoration ecology have an unfortunate temperate terrestrial bioregion bias. This issue is probably the result of these fields developing in the geopolitical north, and both fields should attempt to reconcile this bias.

Second, perhaps because plants tend to dominate most (terrestrial) ecosystems, restoration ecology has developed a strong botanical bias, while conservation biology is more strongly zoological.

Similarly, the principal systemic levels of interest differ between the disciplines. Conservation biology has historically focused on target individuals (i.e. endangered species), and has thus concentrated on genetic and population level dynamics. Since restoration ecology is aimed at rebuilding a functioning ecosystem, a broader (i.e. community or ecosystem) perspective is necessary.

Finally, since soils define the foundation of any functional terrestrial system, restoration ecology's ecosystem-level bias has placed more emphasis on the role of soil physical and microbial processes.

Modes of inquiry

Conservation biology's focus on rare or endangered species limits the number of manipulative studies that can be performed. As a consequence, conservation studies tend to be descriptive, comparative and unreplicated. However, the highly manipulative nature of restoration ecology allows the researcher to more rigorously test hypotheses. In fact, every restorative activity is, in essence, an experimental test of what limits populations.

Crissy Field, San Francisco, before restoration

Crissy Field after restoration

Theoretical foundations

Restoration ecology draws on a wide range of ecological concepts.

Disturbance

Disturbance is a change of environmental conditions, which interferes with the functioning of a biological system. Disturbance at a variety of spatial and temporal scales is a natural, and even essential, component of many communities.

Humans have had limited "natural" impacts on ecosystems for as long as humans have existed, however the severity and scope of our modern influences has accelerated in the last few centuries. Understanding and minimizing the differences between modern anthropogenic and "natural" disturbances is crucial to restoration ecology. For example, new forestry techniques that better imitate historical disturbances are now being implemented.

In addition, restoring a fully sustainable ecosystem often involves studying and attempting to restore a natural disturbance regime (e.g., fire ecology).

Succession

Ecological succession is the process by which the component species of a community changes over time. Following a disturbance, an ecosystem generally progresses from a simple level of organization (i.e. few dominant species) to a more complex community (i.e. many interdependent species) over a few generations. Depending on the severity of the disturbance, restoration often consists of initiating, assisting or accelerating ecological successional processes.

In many ecosystems, communities tend to recover following mild to moderate natural and anthropogenic disturbances. Restoration in these systems involves hastening natural successional trajectories. However, a system that has experienced a more severe disturbance (i.e. physical or chemical alteration of the environment) may require intensive restorative efforts to recreate environmental conditions that favor natural successional processes.

Fragmentation

Habitat fragmentation is the emergence of spatial discontinuities in a biological system. Through land use changes (e.g. agriculture) and "natural" disturbance, ecosystems are broken up into smaller parts. Small fragments of habitat can support only small populations and small populations are more vulnerable to extinction. Further, fragmenting ecosystems decreases interior habitat. Habitat along the edge of a fragment has a different range of environmental conditions and therefore supports different species than the interior. Fragmentation effectively reduces interior habitat and may lead to the extinction of those species which require interior habitat. Restorative projects can increase the effective size of a habitat by simply adding area or by planting habitat corridors that link and fill in the gap between two isolated fragments. Reversing the effects of fragmentation and increasing habitat connectivity are central goals of restoration ecology.

Ecosystem function

Ecosystem function describes the foundational processes of natural systems, including nutrient cycles and energy fluxes. These processes are the most basic and essential components of ecosystems. An understanding of the full complexity and intricacies of these cycles is necessary to address any ecological processes that may be degraded. A functional ecosystem, that is completely self-perpetuating (i.e. no management required), is the ultimate goal of restorative efforts. Because these ecosystem functions are emergent properties of the system as a whole, monitoring and management are crucial for the long-term stability of an ecosystem.

Evolving concepts

Restoration ecology, because of its highly physical nature, is an ideal testing ground for emerging community ecological principles (Bradshaw 1987). There are also the emerging concepts of inventing new and successful restoration technologies, performance standards, time frames, local genetics, and society's relationship to restoration ecology, and new ethical and religious possibilities, as future topics of discussion and debate.

Assembly

Community assembly "is a framework that can unify virtually all of (community) ecology under a single conceptual umbrella". Community assembly theory attempts to explain the existence of environmentally similar sites with differing assemblages of species. It assumes that species have similar niche requirements, so that community formation is a product of random fluctuations from a common species pool. Essentially, if all species are fairly ecologically equivalent then random variation in colonization, migration and extinction rates, between species, drive differences in species composition between sites with comparable environmental conditions.

Stable states

Alternative stable states are discrete species compositional possibilities that may exist within a community. According to assembly theory, differences in species colonization, interspecific interactions and community establishment may result in distinct community species equilibria. A community has numerous possible compositional equilibria that are dependent on the initial assembly. That is, random fluctuations lead to a particular initial community assembly, which affects successional trajectories and the eventual species composition equilibrium.

Multiple stable states is a specific theoretical concept, where all species have equal access to a community (i.e., equal dispersal potential) and differences between communities arise simply because of the timing of each species' colonization.

These concepts are central to restoration ecology; restoring a community involves not only manipulating the timing and structure of the initial species composition, but also working toward a single desired stable state. In fact, a degraded ecosystem may be viewed as an alternative stable state under the altered environmental conditions.

Ontogeny

The ecology of ontogeny is the study of how ecological relationships change over the lifetime of an individual. Organisms require different environmental conditions during different stages of their life-cycle. For immobile organisms (e.g. plants) the conditions necessary for germination and establishment may be different from those of the adult stage. As an ecosystem is altered by anthropogenic processes the range of environmental variables may also be altered. A degraded ecosystem may not include the environmental conditions necessary for a particular stage of an organism's development. If a self-sustaining, functional ecosystem must contain environmental conditions for the perpetual reproduction of its species, restorative efforts must address the needs of organisms throughout their development.

Application of theory

Restoration is defined as the application of ecological theory to ecological restoration. However, for many reasons, this can be a challenging prospect. Here are a few examples of theory informing practice.

Soil heterogeneity effects on community heterogeneity

Spatial heterogeneity of resources can influence plant community composition, diversity and assembly trajectory. Baer et al. (2005) manipulated soil resource heterogeneity in a tallgrass prairie restoration project. They found increasing resource heterogeneity alone was insufficient to insure species diversity in situations where one species may dominate across the range of resource levels. Their findings were consistent with theory regarding the role of ecological filters on community assembly. The establishment of a single species best adapted to the physical and biological conditions can play an inordinately important role in determining community structure.

Invasion, competitive dominance and resource use

"The dynamics of invasive species may depend on their abilities to compete for resources and exploit disturbances relative to the abilities of native species". Seabloom et al. (2003) tested this concept and its implications in a California grassland restoration context. They found native grass species were able to successfully compete with invasive exotics, therefore the possibility exists of restoring an original native grassland ecosystem.

Successional trajectories

Progress along a desired successional pathway may be difficult if multiple stable states exist. Looking at over 40 years of wetland restoration data Klotzi and Gootjans (2001) argue that unexpected and undesired vegetation assemblies "may indicate environmental conditions are not suitable for target communities". Succession may move in unpredicted directions, but constricting environmental conditions within a narrow range may rein in the possible successional trajectories and increase the likelihood of a desired outcome.

Chapter 3

Ecosystem

Coral reefs are an example of a marine ecosystem.

Rainforests often have a great deal of biodiversity with many plant and animal species. This is the Gambia River in Senegal's Niokolo-Koba National Park.

An **ecosystem** is a biological environment consisting of all the organisms living in a particular area, as well as all the nonliving, physical components of the environment with which the organisms interact, such as air, soil, water and sunlight. It is all the organisms in a given area, along with the nonliving (abiotic) factors with which they interact; a biological community and its physical environment.

Overview

The entire array of organisms inhabiting a particular ecosystem is called a community. In a typical ecosystem, plants and other photosynthetic organisms are the producers that provide the food. Ecosystems can be permanent or temporary. Ecosystems usually form a number of food webs.

Ecosystems are functional units consisting of living things in a given area, non-living chemical and physical factors of their environment, linked together through nutrient cycle and energy flow.

1. Natural
    1. Terrestrial ecosystem
    2. Aquatic ecosystem
        1. Lentic, the ecosystem of a lake, pond or swamp.
        2. Lotic, the ecosystem of a river, stream or spring.

2. Artificial, ecosystems created by humans.

Central to the ecosystem concept is the idea that living organisms interact with every other element in their local environment. Eugene Odum, a founder of ecology, stated: "Any unit that includes all of the organisms (ie: 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, and material cycles (i.e.: exchange of materials between living and nonliving parts) within the system is an ecosystem."

Etymology

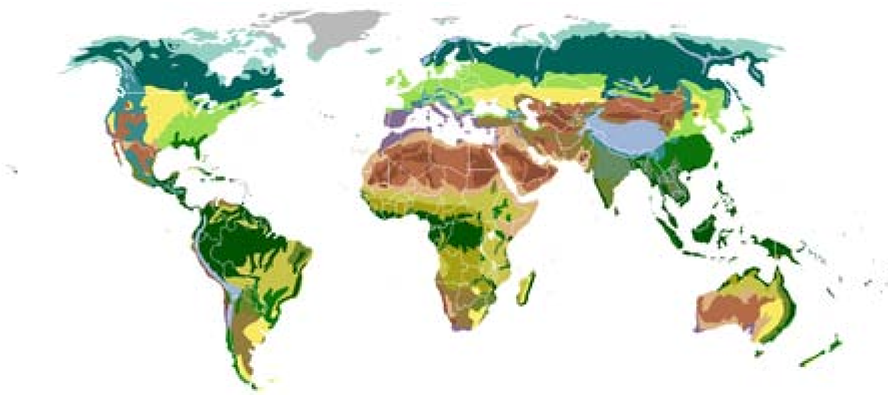
The term ecosystem was coined in 1930 by Roy Clapham to mean the combined physical and biological components of an environment. British ecologist Arthur Tansley later refined the term, describing it as "The whole system, … including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment". Tansley regarded ecosystems not simply as natural units, but as mental isolates. Tansley later defined the spatial extent of ecosystems using the term ecotope.

Examples of ecosystems

- agro-ecosystems
- Agroecosystem
- Aquatic ecosystem
- Chaparral
- Coral reef
- Desert
- Forest
- Greater Yellowstone Ecosystem
- Human ecosystem
- Large marine ecosystem
- Littoral zone
- Lotic
- Marine ecosystem
- Pond Ecosystem
- Prairie
- Rainforest
- Riparian zone
- Savanna
- Steppe
- Subsurface Lithoautotrophic Microbial Ecosystem
- Taiga
- Tundra
- Urban ecosystem

A freshwater ecosystem in Gran Canaria, an island of the Canary Islands.

Biomes



Map of Terrestrial biomes classified by vegetation.

Biomes are a classification of globally similar areas, including ecosystems, such as ecological communities of plants and animals, soil organisms and climatic conditions. Biomes are in part defined based on factors such as plant structures (such as trees, shrubs and grasses), leaf types (such as broadleaf and needleleaf), plant spacing (forest, woodland, savanna) and climate. Unlike ecozones, biomes are not defined by genetic, taxonomic or historical similarities. Biomes are often identified with particular patterns of ecological succession and climax vegetation.

A fundamental classification of biomes is:

1. Terrestrial (land) biomes.
2. Freshwater biomes.
3. Marine biomes.

Classification

Summer field in Belgium (Hamois). The blue flower is Centaurea cyanus and the red one a Papaver rhoeas.

The High Peaks Wilderness Area in the 6,000,000-acre (2,400,000 ha) Adirondack Park is an example of a diverse ecosystem.

Flora of Baja California Desert, Cataviña region, Mexico.

Ecosystems have become particularly important politically, since the Convention on Biological Diversity (CBD) - ratified by 192 countries - defines "the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings" as a commitment of ratifying countries. This has created the political necessity to spatially identify ecosystems and somehow distinguish among them. The CBD defines an "ecosystem" as a "dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".

With the need of protecting ecosystems, the political need arose to describe and identify them efficiently. Vreugdenhil et al. argued that this could be achieved most effectively by using a physiognomic-ecological classification system, as ecosystems are easily recognizable in the field as well as on satellite images. They argued that the structure and seasonality of the associated vegetation, or flora, complemented with ecological data (such as elevation, humidity, and drainage), are each determining modifiers that separate partially distinct sets of species. This is true not only for plant species, but also for species of animals, fungi and bacteria. The degree of ecosystem distinction is subject to the physiognomic modifiers that can be identified on an image and/or in the field. Where necessary, specific fauna elements can be added, such as seasonal concentrations of animals and the distribution of coral reefs.

Several physiognomic-ecological classification systems are available:

- Physiognomic-Ecological Classification of Plant Formations of the Earth: a system based on the 1974 work of Mueller-Dombois and Heinz Ellenberg, and developed by UNESCO. This classificatie "describes the above-ground or underwater vegetation structures and cover as observed in the field, described as plant life forms. This classification is fundamentally a species-independent physiognomic, hierarchical vegetation classification system which also takes into account ecological factors such as climate, elevation, human influences such as grazing, hydric regimes and survival strategies such as seasonality. The system was expanded with a basic classification for open water formations".
- Land Cover Classification System (LCCS), developed by the Food and Agriculture Organization (FAO).
- Forest-Range Environmental Study Ecosystems (FRES) developed by the United States Forest Service for use in the United States.

Several aquatic classification systems are available, and an effort is being made by the United States Geological Survey (USGS) and the Inter-American Biodiversity Information Network (IABIN) to design a complete ecosystem classification system that will cover both terrestrial and aquatic ecosystems.

From a philosophy of science perspective, ecosystems are not discrete units of nature that simply can be identified using the most "correct" type of classification approach. In agreement with the definition by Tansley ("mental isolates"), any attempt to delineate or classify ecosystems should be explicit about the observer/analyst input in the classification including its normative rationale.

Two Giant Sequoias, Sequoia National Park. Note the large fire scar at the base of the right-hand tree; fires do not kill the trees but do remove competing thin-barked species, and aid Giant Sequoia regeneration.

Ecosystem services

Ecosystem services are “fundamental life-support services upon which human civilization depends,”[i] and can be direct or indirect. Examples of direct ecosystem services are: pollination, wood and erosion prevention. Indirect services could be considered climate moderation, nutrient cycles and detoxifying natural substances.

The services and goods an ecosystem provides are often undervalued as many of them are without market value. Broad examples include:

- regulating (climate, floods, nutrient balance, water filtration)
- provisioning (food, medicine, fur)
- cultural (science, spiritual, ceremonial, recreation, aesthetic)
- supporting (nutrient cycling, photosynthesis, soil formation).

Ecosystem legal rights

Ecuador's new constitution of 2008 is the first in the world to recognize legally enforceable Rights of Nature, or ecosystem rights.

The borough of Tamaqua, Pennsylvania passed a law giving ecosystems legal rights. The ordinance establishes that the municipal government or any Tamaqua resident can file a lawsuit on behalf of the local ecosystem. Other townships, such as Rush, followed suit and passed their own laws.

This is part of a growing body of legal opinion proposing 'wild law'. Wild law, a term coined by Cormac Cullinan (a lawyer based in South Africa), would cover birds and animals, rivers and deserts.

Function and biodiversity

Savanna at Ngorongoro Conservation Area, Tanzania.

The side of a tide pool showing sea stars (*Dermasterias*), sea anemones (*Anthopleura*) and sea sponges in Santa Cruz, California.

From an anthropocentric point of view, some people perceive ecosystems as production units that produce goods and services, such as wood by forest ecosystems and grass for cattle by natural grasslands. Meat from wild animals, often referred to as bush meat in Africa, has proven to be extremely successful under well-controlled management schemes in South Africa and Kenya. Much less successful has been the discovery and commercialization of substances of wild organism for pharmaceutical purposes. Services derived from ecosystems are referred to as ecosystem services. They may include

1. facilitating the enjoyment of nature, which may generate many forms of income and employment in the tourism sector, often referred to as eco-tourisms,
2. water retention, thus facilitating a more evenly distributed release of water,
3. soil protection, open-air laboratory for scientific research, etc.

A greater degree of species or biological diversity - commonly referred to as Biodiversity - of an ecosystem may contribute to greater resilience of an ecosystem, because there are more species present at a location to respond to change and thus "absorb" or reduce its effects. This reduces the effect before the ecosystem's structure is fundamentally changed to a different state. This is not universally the case and there is no proven relationship between the species diversity of an ecosystem and its ability to provide goods and services on a sustainable level: Humid tropical forests produce very few goods and direct services and are extremely vulnerable to change, while many temperate forests readily grow back to their previous state of development within a lifetime after felling or a forest fire. Some grasslands have been sustainably exploited for thousands of years (Mongolia, Africa, European peat and mooreland communities).

The study of ecosystems

Forest on San Juan Island

Ecosystem dynamics

Loch Lomond in Scotland forms a relatively isolated ecosystem. The fish community of this lake has remained unchanged over a very long period of time.

Introduction of new elements, whether biotic or abiotic, into an ecosystem tend to have a disruptive effect. In some cases, this can lead to ecological collapse or "trophic cascading" and the death of many species within the ecosystem. Under this deterministic vision, the abstract notion of ecological health attempts to measure the robustness and recovery capacity for an ecosystem; i.e. how far the ecosystem is away from its steady state.

Often, however, ecosystems have the ability to rebound from a disruptive agent. The difference between collapse or a gentle rebound is determined by two factors—the toxicity of the introduced element and the resiliency of the original ecosystem.

Ecosystems are primarily governed by stochastic (chance) events, the reactions these events provoke on non-living materials and the responses by organisms to the conditions surrounding them. Thus, an ecosystem results from the sum of individual responses of organisms to stimuli from elements in the environment.The presence or absence of populations merely depends on reproductive and dispersal success, and population levels fluctuate in response to stochastic events. As the number of species in an ecosystem is higher, the number of stimuli is also higher. Since the beginning of life organisms have survived continuous change through natural selection of successful feeding, reproductive and dispersal behavior. Through natural selection the planet's species have continuously adapted to change through variation in their biological composition and distribution. Mathematically it can be demonstrated that greater numbers of different interacting factors tend to dampen fluctuations in each of the individual factors.

Spiny forest at Ifaty, Madagascar, featuring various Adansonia (baobab) species, Alluaudia procera (Madagascar ocotillo) and other vegetation.

Given the great diversity among organisms on earth, most ecosystems only changed very gradually, as some species would disappear while others would move in. Locally, sub-populations continuously go extinct, to be replaced later through dispersal of other sub-populations. Stochastists do recognize that certain intrinsic regulating mechanisms occur in nature. Feedback and response mechanisms at the species level regulate population levels, most notably through territorial behaviour. Andrewatha and Birch suggest that territorial behaviour tends to keep populations at levels where food supply is not a limiting factor. Hence, stochastists see territorial behaviour as a regulatory mechanism at the species level but not at the ecosystem level. Thus, in their vision, ecosystems are not regulated by feedback and response mechanisms from the ecosystem itself and there is no such thing as a balance of nature.

If ecosystems are governed primarily by stochastic processes, through which its subsequent state would be determined by both predictable and random actions, they may be more resilient to sudden change than each species individually. In the absence of a balance of nature, the species composition of ecosystems would undergo shifts that would depend on the nature of the change, but entire ecological collapse would probably be infrequent events.

Arctic tundra on Wrangel Island, Russia.

The theoretical ecologist Robert Ulanowicz has used information theory tools to describe the structure of ecosystems, emphasizing mutual information (correlations) in studied systems. Drawing on this methodology and prior observations of complex ecosystems, Ulanowicz depicts approaches to determining the stress levels on ecosystems and predicting system reactions to defined types of alteration in their settings (such as increased or reduced energy flow, and eutrophication.

In addition, Eric Sanderson has developed the Muir web, based on experience on the Mannahatta project. This graphical schematic shows how different species are connected to each other, not only regarding their position in the food chain, but also regarding other services, i.e. provisioning of shelter.

Ecosystem ecology

Ecosystem ecology is the integrated study of biotic and abiotic components of ecosystems and their interactions within an ecosystem framework. This science examines how ecosystems work and relates this to their components such as chemicals, bedrock, soil, plants, and animals. Ecosystem ecology examines physical and biological structure and examines how these ecosystem characteristics interact.

Chapter 4

Ecosystem Model

Ecosystem models, or **ecological models**, are mathematical representations of ecosystems. Typically they simplify complex foodwebs down to their major components or trophic levels, and quantify these as either numbers of organisms, biomass or the inventory/concentration of some pertinent chemical element (for instance, carbon or a nutrient species such as nitrogen or phosphorus).

Overview

Complexity

Ecosystem models are a development of theoretical ecology that aim to characterise the major dynamics of ecosystems, both to synthesise the understanding of such systems and to allow predictions of their behaviour (in general terms, or in response to particular changes).

Because of the complexity of ecosystems (in terms of numbers of species/ecological interactions), ecosystem models typically simplify the systems they are studying to a limited number of pragmatic components. These may be particular species of interest, or may be broad functional types such as autotrophs, heterotrophs or saprotrophs. In biogeochemistry, ecosystem models usually include representations of non-living "resources" such as nutrients, which are consumed by (and may be depleted by) living components of the model.

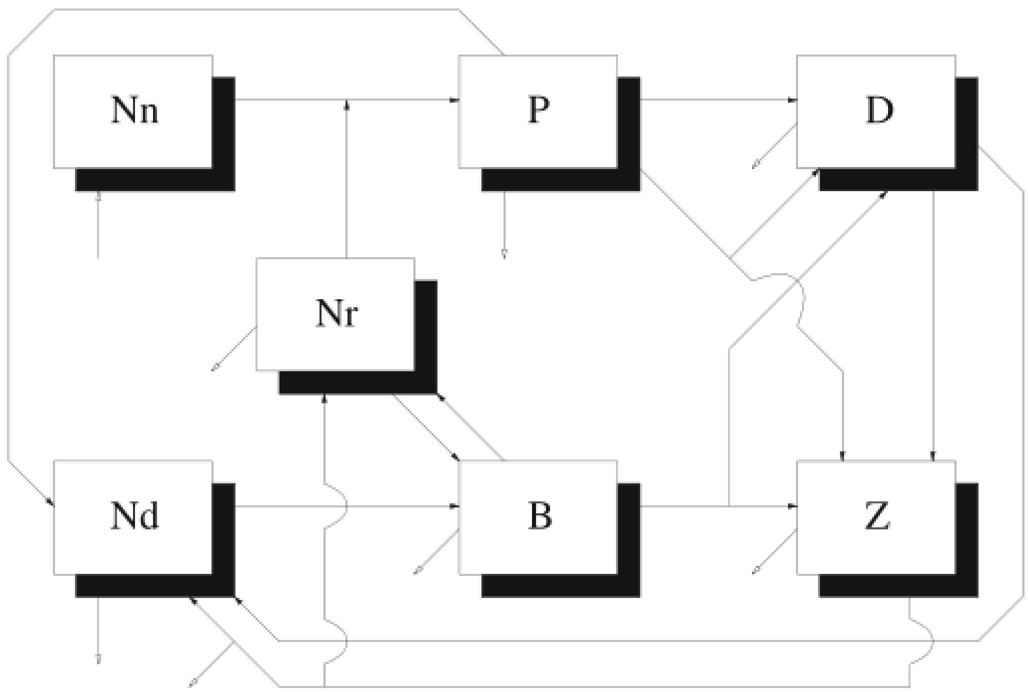
This simplification is driven by a number of factors:

- **Ignorance**: while understood in broad outline, the details of a particular foodweb may not be known; this applies both to identifying relevant species, and to the functional responses linking them (which are often extremely difficult to quantify)
- **Computation**: practical constraints on simulating large numbers of ecological elements; this is particularly true when ecosystem models are embedded within

other spatially-resolved models (such as physical models of terrain or ocean bodies, or idealised models such as cellular automata or coupled map lattices)

- **Understanding**: depending upon the nature of the study, complexity can confound the analysis of an ecosystem model; the more interacting components a model has, the less straightforward it is to extract and separate causes and consequences; this is compounded when uncertainty about components obscures the accuracy of a simulation

Structure



A structural diagram of an example model. This shows the Fasham, Ducklow & McKelvie (1990) open ocean plankton ecosystem model.

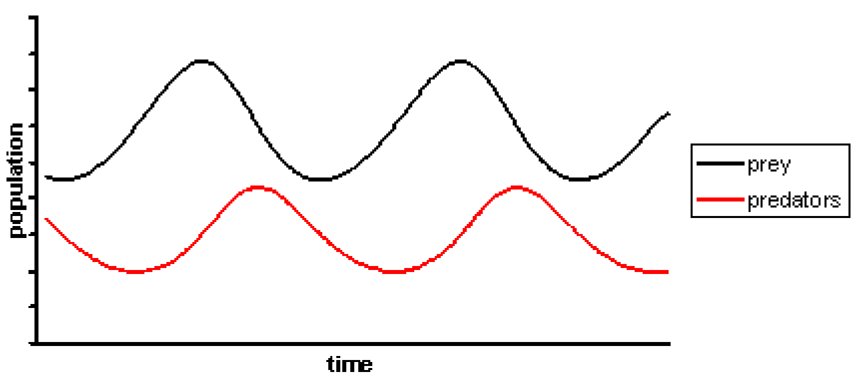
The process of simplification described above typically reduces an ecosystem to a small number of state variables. Depending upon the system under study, these may represent ecological components in terms of numbers of discrete individuals or quantify the component more continuously as a measure of the total biomass of all organisms of that type, often using a common model currency (e.g. mass of carbon per unit area/volume).

The components are then linked together by mathematical functions that describe the nature of the relationships between them. For instance, in models which include predator-prey relationships, the two components are usually linked by some function that relates total prey captured to the populations of both predators and prey. Deriving these relationships is often extremely difficult given habitat heterogeneity, the details of component behavioral ecology (including issues such as perception, foraging behaviour), and the difficulties involved in unobtrusively studying these relationships under field conditions.

Typically relationships are derived statistically or heuristically. For example, some standard functional forms describing these relationships are linear, quadratic, hyperbolic or sigmoid functions. The latter two are known in ecology as type II and type III responses, named by C. S. Holling in early, groundbreaking work on predation in mammals. Both describe relationships in which a linkage between components saturates at some maximum rate (e.g. above a certain concentration of prey organisms, predators cannot catch any more per unit time). Some ecological interactions are derived explicitly from the biochemical processes that underlie them; for instance, nutrient processing by an organism may saturate because of either a limited number of binding sites on the organism's exterior surface or the rate of diffusion of nutrient across the boundary layer surrounding the organism.

After establishing the components to be modelled and the relationships between them, another important factor in ecosystem model structure is the representation of space used. Historically, models have often ignored the confounding issue of space, utilising zero-dimensional approaches, such as ordinary differential equations. With increases in computational power, models which incorporate space are increasingly used (e.g. partial differential equations, cellular automata). This inclusion of space permits dynamics not present in non-spatial frameworks, and illuminates processes that lead to pattern formation in ecological systems.

Examples



A sample time-series of the Lotka-Volterra model. Note that the two populations exhibit cyclic behaviour, and that the predator cycle lags behind that of the prey.

One of the earliest, and most well-known, ecological models is the predator-prey model of Alfred J. Lotka (1925) and Vito Volterra (1926). This model takes the form of a pair of ordinary differential equations, one representing a prey species, the other its predator.

$$\frac{dX}{dt} = \alpha.X - \beta.X.Y$$
$$\frac{dY}{dt} = \gamma.\beta.X.Y - \delta.Y$$

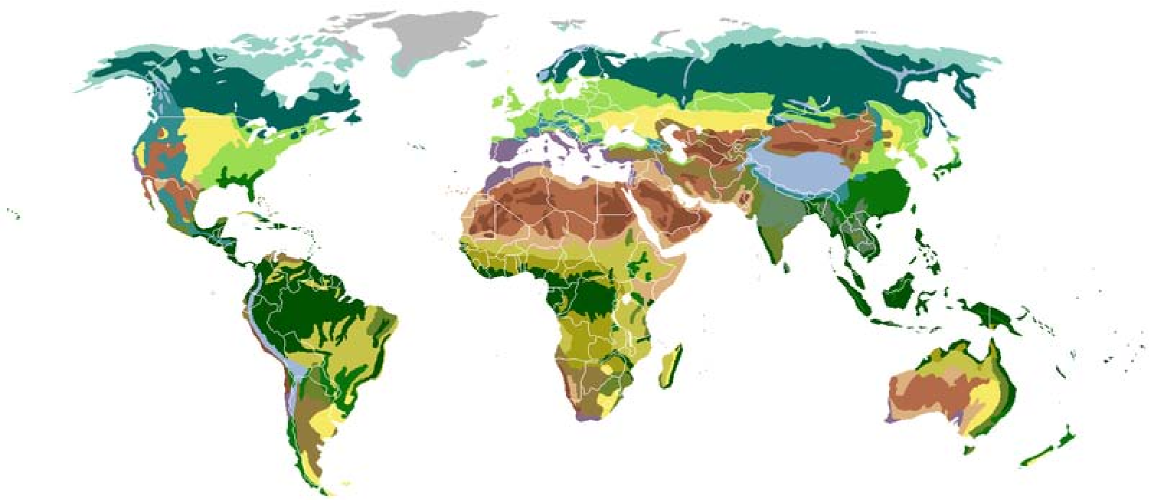
where,

- *X* is the number/concentration of the prey species;
- *Y* is the number/concentration of the predator species;
- α is the prey species' growth rate;
- β is the predation rate of *Y* upon *X*;
- γ is the assimilation efficiency of *Y*;
- δ is the mortality rate of the predator species

Volterra originally devised the model to explain fluctuations in fish and shark populations observed in the Adriatic Sea after the First World War (when fishing was curtailed). However, the equations have subsequently been applied more generally. Although simple, they illustrate some of the salient features of ecological models: modelled biological populations experience growth, interact with other populations (as either predators, prey or competitors) and suffer mortality.

Chapter 5

Ecology



The scientific discipline of **ecology** encompasses areas from global processes (above), to the study of marine and terrestrial habitats (middle) to interspecific interactions such as predation and pollination (below).

Ecology (from Greek: οἶκος, "house"; -λογία, "study of") is the scientific study of the relation of living organisms with each other and their surroundings. Ecosystems are defined by a web, community, or network of individuals that arrange into a self-organized and complex hierarchy of pattern and process. Ecosystems create a biophysical feedback between living (biotic) and nonliving (abiotic) components of an environment that generates and regulates the biogeochemical cycles of the planet. Ecosystems provide goods and services that sustain human societies and general well-being. Ecosystems are sustained by biodiversity within them. Biodiversity is the full-scale of life and its processes, including genes, species and ecosystems forming lineages that integrate into a complex and regenerative spatial arrangement of types, forms, and interactions.

Ecology is a sub-discipline of biology, the study of life. The word "ecology" ("oekologie") was coined in 1866 by the German scientist Ernst Haeckel (1834–1919). Haeckel was a zoologist, artist, writer, and later in life a professor of comparative anatomy. Ancient philosophers of Greece, including Hippocrates and Aristotle, were among the earliest to record notes and observations on the natural history of plants and animals; the early rudiments of modern ecology. Modern ecology mostly branched out of natural history science that flourished in the late 19th century. Charles Darwin's evolutionary treatise and the concept of adaptation as it was introduced in 1859 is a pivotal cornerstone in modern ecological theory.

Ecology is not synonymous with environment, environmentalism, natural history or environmental science. Ecology is closely related to the biological disciplines of physiology, evolution, genetics and behavior. An understanding of how biodiversity affects ecological function is an important focus area in ecological studies. Ecosystems sustain every life-supporting function on the planet, including climate regulation, water filtration, soil formation (pedogenesis), food, fibers, medicines, erosion control, and many other natural features of historical, spiritual or scientific value.

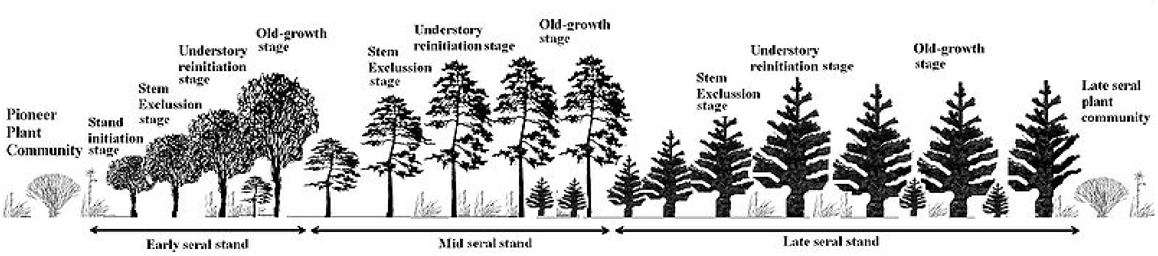
Ecologists seek to explain:

- life processes and adaptations
- distribution and abundance of organisms
- the movement of materials and energy through living communities
- the successional development of ecosystems, and
- the abundance and distribution of biodiversity in context of the environment.

There are many practical applications of ecology in conservation biology, wetland management, natural resource management (agriculture, forestry, fisheries), city planning (urban ecology), community health, economics, basic & applied science and it provides a conceptual framework for understanding and researching human social interaction (human ecology).

Levels of organization and study

Scale and complexity



Ecosystems regenerate after a disturbance such as fire, forming mosaics of different age groups structured across a landscape. Pictured are different seral stages in forested ecosystems starting from pioneers colonizing a disturbed site and maturing in successional stages leading to old-growth forests.

Ecosystems are forever confronted with a range of natural environmental fluctuations that vary transiently in magnitude through space and time. It can take thousands of years for ecological processes to mature; the life-span of a tree, for example, can encompass different successional stages. The ecological process is extended even further through time as trees die, decay and provide habitat as nurse logs or coarse woody debris. The area of an ecosystem can vary greatly from tiny to vast. A single tree is of little consequence to the classification of a forest ecosystem, but critically relevant to the smaller organisms living in and on it. Several generations of an aphid population can exist over the lifespan of a single leaf. Each of those aphids, in turn, support diverse bacterial communities. Fine scale structure of aphid populations can be constrained by top-down influences of tree growth that is related to site specific variables, such as soil type, moisture content, slope of the land, and forest canopy closure. Likewise, finer scale dynamics operating in the aphid populations can impart bottom-up influence on tree growth rates. The scale of ecological dynamics can operate as a closed island with respect to local site variables, such as aphids migrating on a tree, while at the same time remain open with regard to broader scale influences, such as atmosphere or climate. Hence, ecologists have devised means of hierarchically classifying ecosystems by analyzing data collected from finer scale units, such as vegetation associations, climate, and soil types, and integrate this information to identify larger emergent patterns of uniform organization and processes that operate on regional, local, and chronological scales.

There are different views on complexity and how it relates to ecology. One perspective lumps things that we do not understand into this category by virtue of the computational effort it would require to piece together the numerous interacting parts. Alternatively, complexity in life sciences can be viewed as emergent self-organized systems with multiple possible outcomes directed by random accidents of history; an extension of the first perspective. Global patterns of biological diversity are complex. This biocomplexity stems from the interplay among ecological processes that operate and influence patterns that grade into each other, such as transitional areas or ecotones that stretch across different scales. "Complexity in ecology is of at least six distinct types: spatial, temporal, structural, process, behavioral, and geometric. Small scale patterns do not necessarily explain large scale phenomena, otherwise captured in the expression 'the sum is greater than the parts'. Ecologists have identified emergent and self-organizing phenomena that operate at different environmental scales of influence, ranging from molecular to planetary, and these require different sets of scientific explanation. Long-term ecological studies provide important track records to better understand the complexity of ecosystems over longer temporal and broader spatial scales. The International Long Term Ecological Network manages and exchanges scientific information among research sites. The longest experiment in existence is the Park Grass Experiment that was initiated in 1856. Another example includes the Hubbard Brook study in operation since 1960.

To structure the study of ecology into a manageable framework of understanding, the biological world is conceptually organized as a nested hierarchy of organization, ranging in scale from genes, to cells, to tissues, to organs, to organisms, to species and up to the level of the biosphere. Together these hierarchical scales of life form a panarchy. Ecosystems are primarily researched at three key levels of organization—organisms, populations, and communities. Ecologists study ecosystems by sampling a certain number of individuals that are representative of a population. Ecosystems consist of communities interacting with each other and the environment. In ecology, communities are created by the interaction of the populations of different species in an area.

Biodiversity

Biodiversity is the variety of life and its processes. It includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, yet ever changing and adapting.[:5]

Biodiversity (an abbreviation of biological diversity) describes the diversity of life from genes to ecosystems and spans every level of biological organization. Biodiversity means different things to different people and there are many ways to index, measure, characterize, and represent its complex organization. Biodiversity includes species diversity, ecosystem diversity, genetic diversity and the complex processes operating at and among these respective levels. Biodiversity plays an important role in ecological health as much as it does for human health. Preventing or prioritizing species extinctions is one way to preserve biodiversity, but populations, the genetic diversity within them and ecological processes, such as migration, are being threatened on global scales and disappearing rapidly as well. Conservation priorities and management techniques require different approaches and considerations to address the full ecological scope of biodiversity. Populations and species migration, for example, are more sensitive indicators of ecosystem services that sustain and contribute natural capital toward the well-being of humanity. An understanding of biodiversity has practical application for ecosystem-based conservation planners as they make ecologically responsible decisions in management recommendations to consultant firms, governments and industry.

Niche and habitat

Termite mounds with varied heights of chimneys regulate gas exchange, temperature and other environmental parameters that are needed to sustain the internal physiology of the entire colony.

There are many definitions of the niche dating back to 1917, but G. Evelyn Hutchinson made conceptual advances in 1957 and introduced the most widely accepted definition: "The niche is the set of biotic and abiotic conditions in which a species is able to persist and maintain stable population sizes." The ecological niche is a central concept in the ecology of organisms and is sub-divided into the *fundamental* and the *realized* niche. The fundamental niche is the set of environmental conditions under which a species is able to persist. The realized niche is the set of environmental plus ecological conditions under which a species persists. The Hutchisonian niche is defined more technically as an "euclidean hyperspace whose *dimensions* are defined as environmental variables and whose *size* is a function of the number of values that the environmental values may assume for which an organism has *positive fitness*."

The habitat of a species is a related but distinct concept that describes the environment over which a species is known to occur and the type of community that is formed as a result. More specifically, "habitats can be defined as regions in environmental space that are composed of multiple dimensions, each representing a biotic or abiotic environmental variable; that is, any component or characteristic of the environment related directly (e.g. forage biomass and quality) or indirectly (e.g. elevation) to the use of a location by the animal." For example, the habitat might refer to an aquatic or terrestrial environment that can be further categorized as montane or alpine ecosystems.

Biogeographical patterns and range distributions are explained or predicted through knowledge and understanding of a species traits and niche requirements. Species have functional traits that are uniquely adapted to the ecological niche. A trait is a measurable property, phenotype, or characteristic of an organism that influences its performance. Genes play an important role in the development and expression of traits. Resident species evolve traits that are fitted to their local environment. This tends to afford them a competitive advantage and discourages similarly adapted species from having an overlapping geographic range. The competitive exclusion principle suggests that two species cannot coexist indefinitely by living off the same limiting resource. When similarly adapted species are found to overlap geographically, closer inspection reveals subtle ecological differences in their habitat or dietary requirements. Lately this paradigm has been refuted because there are many examples of species that do follow exactly the same successful strategy. A familiar example being the Chiffchaff and the Willow Warbler, but also trees in a rain forest, very similar water beetles , algae and prairie birds can be very similar. Mathematical modelling has shown that two successful strategies are possible: being similar enough to a successful species, or being dissimilar enough. According to the models it is the lumps of very similar species can take the classical place of the species in the competitive exclusion principle based models.

Biodiversity of a coral reef. Corals adapt and modify their environment by forming calcium carbonate skeletons that provide growing conditions for future generations and form habitat for many other species.

Niche construction

Organisms are subject to environmental pressures, but they are also modifiers of their habitats. The regulatory feedback between organisms and their environment can modify conditions from local (e.g., a beaver pond) to global scales (e.g., Gaia), over time and even after death, such as decaying logs or silica skeleton deposits from marine organisms. The process and concept of ecosystem engineering has also been called niche construction. Ecosystem engineers are defined as: "...organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In so doing they modify, maintain and create habitats."

The ecosystem engineering concept has stimulated a new appreciation for the degree of influence that organisms have on the ecosystem and evolutionary process. The terms niche construction are more often used in reference to the under appreciated feedback mechanism of natural selection imparting forces on the abiotic niche. An example of natural selection through ecosystem engineering occurs in the nests of social insects, including ants, bees, wasps, and termites. There is an emergent homeostasis or homeorhesis in the structure of the nest that regulates, maintains and defends the physiology of the entire colony. Termite mounds, for example, maintain a constant internal temperature through the design of air-conditioning chimneys. The structure of the nests themselves are subject to the forces of natural selection. Moreover, the nest can survive over successive generations, which means that ancestors inherit both genetic material and a legacy niche that was constructed before their time.

Population ecology

The population is the unit of analysis in population ecology. A population consists of individuals of the same species that live, interact and migrate through the same niche and habitat. A primary law of population ecology is the Malthusian growth model. This law states that:

"...a population will grow (or decline) exponentially as long as the environment experienced by all individuals in the population remains constant.

This Malthusian premise provides the basis for formulating predictive theories and tests that follow. Simplified population models usually start with four variables including death, birth, immigration, and emigration. Mathematical models are used to calculate changes in population demographics using a null model. A null model is used as a null hypothesis for statistical testing. The null hypothesis states that random processes create observed patterns. Alternatively the patterns differ significantly from the random model and require further explanation. Models can be mathematically complex where "...several competing hypotheses are simultaneously confronted with the data." An example of an introductory population model describes a closed population, such as on an island, where immigration and emigration does not take place. In these island models the rate of population change is described by:

$$\frac{dN}{dT} = B - D = bN - dN = (b - d)N = rN,$$

where N is the total number of individuals in the population, B is the number of births, D is the number of deaths, b and d are the per capita rates of birth and death respectively, and r is the per capita rate of population change. This formula can be read out as the rate of change in the population (dN/dT) is equal to births minus deaths (B – D).

Using these modelling techniques, Malthus' population principle of growth was later transformed into a model known as the logistic equation:

$$\frac{dN}{dT} = aN(1 - \frac{N}{K}),$$

where *N* is the number of individuals measured as biomass density, *a* is the maximum per-capita rate of change, and *K* is the carrying capacity of the population. The formula can be read as follows: the rate of change in the population (*dN/dT*) is equal to growth (*aN*) that is limited by carrying capacity *(1 – N/K)*. The discipline of population ecology builds upon these introductory models to further understand demographic processes in real study populations and conduct statistical tests. The field of population ecology often uses data on life history and matrix algebra to develop projection matrices on fecundity and survivorship. This information is used for managing wildlife stocks and setting harvest quotas.

A list of terms that define various types of natural groupings of individuals that are used in population studies

Term	Definition
Species population	All individuals of a species.
Metapopulation	A set of spatially disjunct populations, among which there is some immigration.
Population	A group of conspecific individuals that is demographically, genetically, or spatially disjunct from other groups of individuals.
Aggregation	A spatially clustered group of individuals.
Deme	A group of individuals more genetically similar to each other than to other individuals, usually with some degree of spatial isolation as well.
Local population	A group of individuals within an investigator-delimited area smaller than the geographic range of the species and often within a population (as defined above). A local population could be a disjunct population as well.
Subpopulation	An arbitrary spatially delimited subset of individuals from within a population (as defined above).

Metapopulation ecology

Populations are also studied and modeled according to the metapopulation concept. The metapopulation concept was introduced in 1969: "as a population of populations which go extinct locally and recolonize.": Metapopulation ecology is another statistical approach that is often used in conservation research. Metapopulation research simplifies the landscape into patches of varying levels of quality.

In metapopulation terminology there are emigrants (individuals that leave a patch), immigrants (individuals that move into a patch) and sites are classed either as sources or sinks. A site is a generic term that refers to places where ecologists sample populations, such as ponds or defined sampling areas in a forest. Source patches are productive sites that generate a seasonal supply of juveniles that migrate to other patch locations. Sink patches are unproductive sites that only receive migrants and will go extinct unless rescued by an adjacent source patch or environmental conditions become more favorable. Metapopulation models examine patch dynamics over time to answer questions about spatial and demographic ecology. The ecology of metapopulations is a dynamic process of extinction and colonization. Small patches of lower quality (i.e., sinks) are maintained or rescued by a seasonal influx of new immigrants. A dynamic metapopulation structure evolves from year to year, where some patches are sinks in dry years and become sources when conditions are more favorable. Ecologists use a mixture of computer models and field studies to explain metapopulation structure.

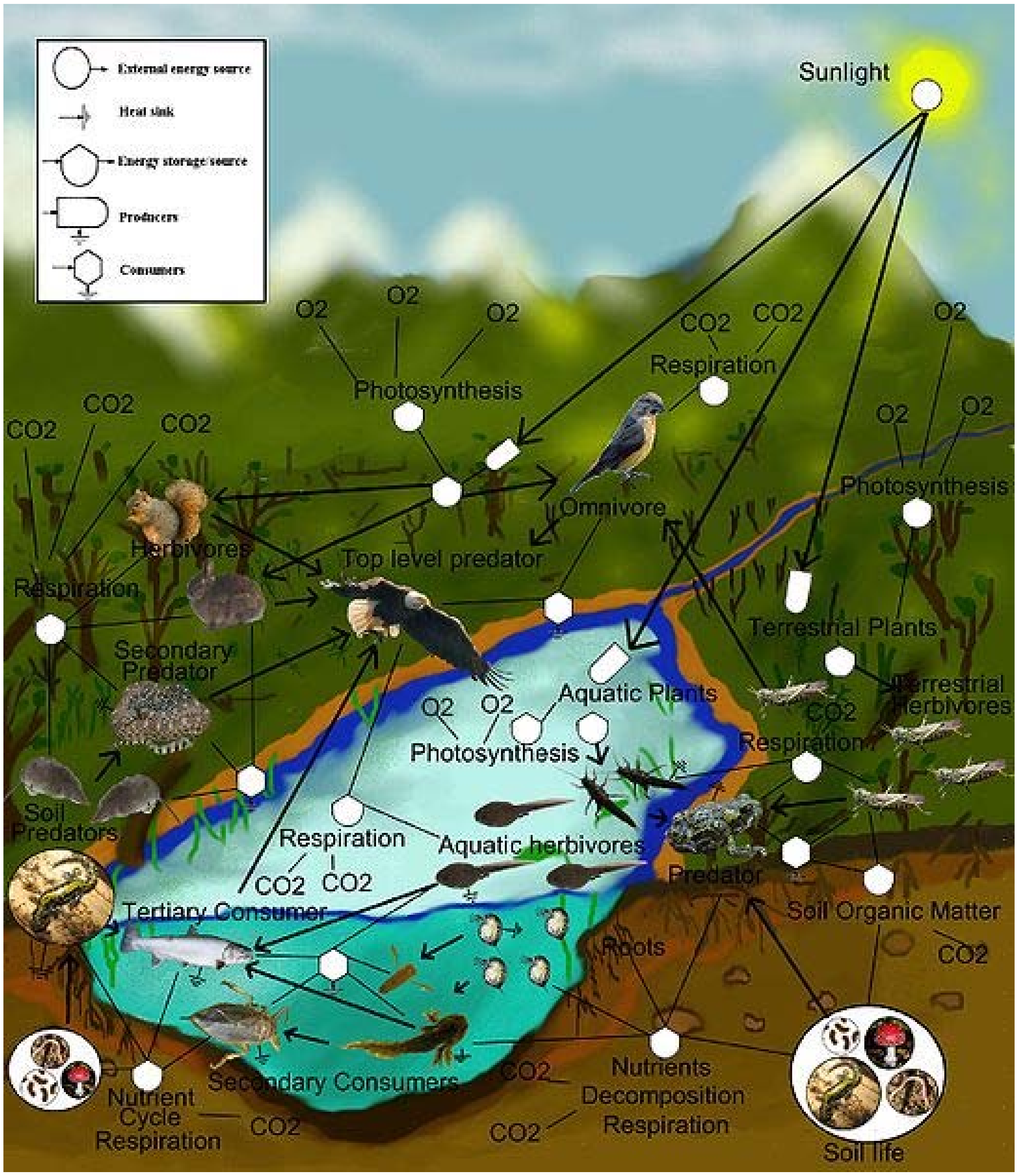
Community ecology

> Community ecology examines how interactions among species and their environment affect the abundance, distribution and diversity of species within communities.
>
> Johnson & Stinchcomb

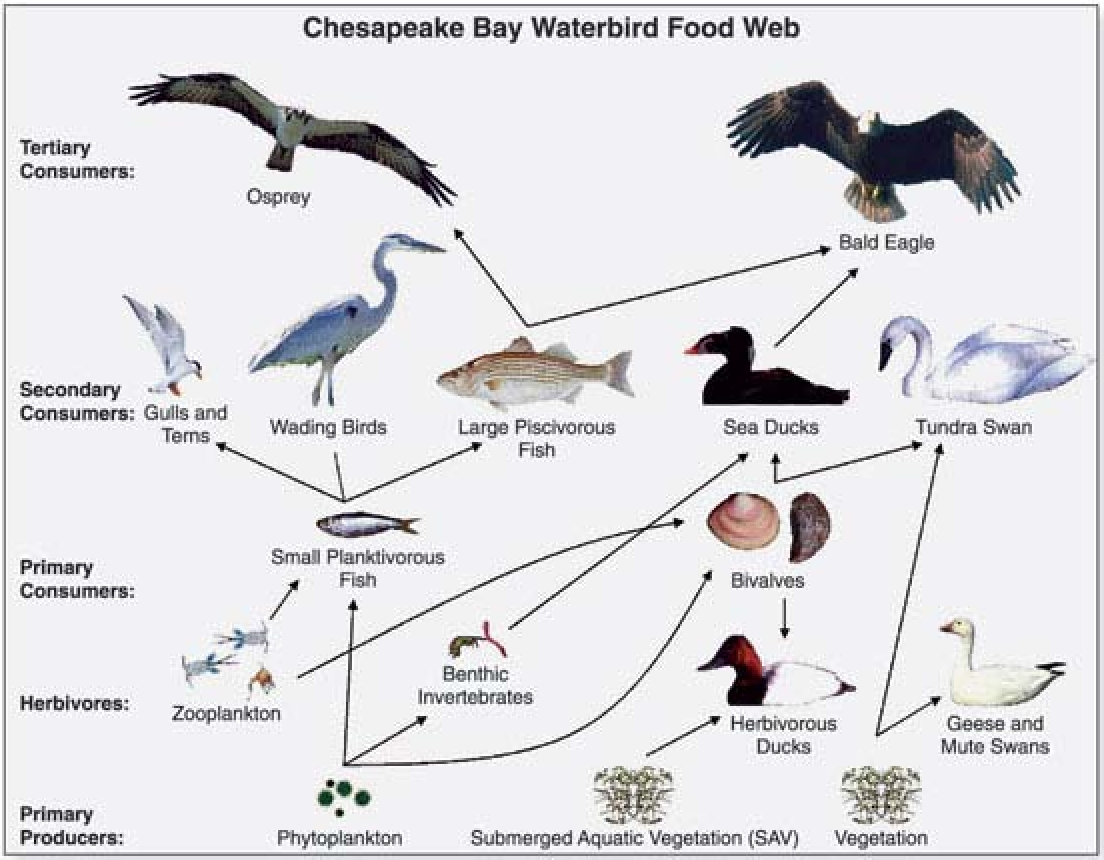
Community ecology is the study of the interactions among a collection of interdependent species that cohabitate the same geographic area. An example of a study in community ecology might measure primary production in a wetland in relation to decomposition and consumption rates. This requires an understanding of the community connections between plants (i.e., primary producers) and the decomposers (e.g., fungi and bacteria). or the analysis of predator-prey dynamics affecting amphibian biomass. Food webs and trophic levels are two widely employed conceptual models used to explain the linkages among species.

Food webs

A food web is the archetypal ecological network. They are a type of concept map that illustrate pathways of energy flows in an ecological community, usually starting with solar energy being used by plants during photosynthesis. As plants grow, they accumulate carbohydrates and are eaten by grazing herbivores. Step by step lines or relations are drawn until a web of life is illustrated.



Freshwater aquatic and terrestrial food-webs



Generalized food web of waterbirds from Chesapeake Bay

There are different ecological dimensions that can be mapped to create more complicated food webs, including: species composition (type of species), richness (number of species), biomass (the dry weight of plants and animals), productivity (rates of conversion of energy and nutrients into growth), and stability (food webs over time). A food web diagram illustrating species composition shows how change in a single species can directly and indirectly influence many others. Microcosm studies are used to simplify food web research into semi-isolated units such as small springs, decaying logs, and laboratory experiments using organisms that reproduce quickly, such as daphnia feeding on algae grown under controlled environments in jars of water.

Principles gleaned from food web microcosm studies are used to extrapolate smaller dynamic concepts to larger systems. Food webs are limited because they are generally restricted to a specific habitat, such as a cave or a pond. The food web illustration (right) only shows a small part of the complexity connecting the aquatic system to the adjacent terrestrial land. Many of these species migrate into other habitats to distribute their effects on a larger scale. In other words, food webs are incomplete, but are nonetheless a valuable tool in understanding community ecosystems.

Trophic dynamics

The Greek root of the word *troph*, τροφή, trophē, means food or feeding. Links in food-webs primarily connect feeding relations or trophism among species. Biodiversity within ecosystems can be organized into vertical and horizontal dimensions. The vertical dimension represents feeding relations that become further removed from the base of the food chain up toward top predators. The horizontal dimension represents the abundance or biomass at each level. When the relative abundance or biomass of each functional feeding group is stacked into their respective trophic levels they naturally sort into a 'pyramid of numbers'. Functional groups are broadly categorized as autotrophs (or primary producers), heterotrophs (or consumers), and detrivores (or decomposers). Heterotrophs can be further sub-divided into different functional groups, including: primary consumers (strict herbivores), secondary consumers (predators that feed exclusively on herbivores) and tertiary consumers (predators that feed on a mix of herbivores and predators). Omnivores do not fit neatly into a functional category because they eat both plant and animal tissues. It has been suggested that omnivores have a greater functional influence as predators because relative to herbivores they are comparatively inefficient at grazing.

The decomposition of dead organic matter, such as leaves falling on the forest floor, turns into soils that feed plant production. The total sum of the planet's soil ecosystems is called the pedosphere where a very large proportion of the Earth's biodiversity sorts into other trophic levels. Invertebrates that feed and shred larger leaves, for example, create smaller bits for smaller organisms in the feeding chain. Collectively, these are the detrivores that regulate soil formation. Tree roots, fungi, bacteria, worms, ants, beetles, centipedes, spiders, mammals, birds, reptiles, amphibians and other less familiar creatures all work to create the trophic web of life in soil ecosystems. As organisms feed and migrate through soils they physically displace materials, which is an important ecological process called bioturbation. Biomass of soil microorganisms are influenced by and feed back into the trophic dynamics of the exposed solar surface ecology. Paleoecological studies of soils places the origin for bioturbation to a time before the Cambrian period. Other events, such as the evolution of trees and amphibians moving into land in the Devonian period played a significant role in the development of soils and ecological trophism.

List of ecological functional groups, definitions and examples

Functional group	Definition and examples
Producers or *autotrophs*	Usually plants or cyanobacteria that are capable of photosynthesis but could be other organisms such as the bacteria near ocean vents that are capable of chemosynthesis.
Consumers or *heterotrophs*	Animals, which can be primary consumers (herbivorous), or secondary or tertiary consumers (carnivorous and omnivores).
Decomposers or *detritivores*	Bacteria, fungi, and insects which degrade organic matter of all types and restore nutrients to the environment. The producers will then consume the nutrients, completing the cycle.

Functional trophic groups sort out hierarchically into pyramidic trophic levels because it requires specialized adaptations to become a photosynthesizer or a predator, so few organisms have the adaptations needed to combine both abilities. This explains why functional adaptations to trophism (feeding) organizes different species into emergent functional groups. Trophic levels are part of the holistic or complex systems view of ecosystems. Each trophic level contains unrelated species that grouped together because they share common ecological functions. Grouping functionally similar species into a trophic system gives a macroscopic image of the larger functional design.

Keystone species

A keystone species is a species that is disproportionately connected to more species in the food-web. Keystone species have lower levels of biomass in the trophic pyramid relative to the importance of their role. The many connections that a keystone species holds means that it maintains the organization and structure of entire communities. The loss of a keystone species results in a range of dramatic cascading effects that alters trophic dynamics, other food-web connections and can cause the extinction of other species in the community.

Sea otters (*Enhydra lutris*) are commonly cited as an example of a keystone species because they limit the density of sea urchins that feed on kelp. If sea otters are removed from the system, the urchins graze until the kelp beds disappear and this has a dramatic effect on community structure. Hunting of sea otters, for example, is thought to have indirectly led to the extinction of the Steller's Sea Cow (*Hydrodamalis gigas*). While the keystone species concept has been used extensively as a conservation tool, it has been criticized for being poorly defined from an operational stance. It is very difficult to experimentally determine in each different ecosystem what species may hold a keystone role. Furthermore, food-web theory suggests that keystone species may not be all that common. It is therefore unclear how generally the keystone species model can be applied.

Ecosystem ecology

> These ecosystems, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom.
>
> Tansley[:299]

The concept of the ecosystem was first introduced in 1935 to describe habitats within biomes that form an integrated whole and a dynamically responsive system having both physical and biological complexes. Within an ecosystem there are inseparable ties that link organisms to the physical and biological components of their environment to which they are adapted. Ecosystems are complex adaptive systems where the interaction of life processes form self-organizing patterns across different scales of time and space. This section introduces key areas of ecosystem ecology that are used to inquire, understand and explain observed patterns of biodiversity and ecosystem function across different scales of organization.

Biome

Ecological units of organization are defined through reference to any magnitude of space and time on the planet. Communities of organisms, for example, are somewhat arbitrarily defined, but the processes of life integrate at different levels and organize into more complex wholes. Biomes, for example, are a larger unit of organization that categorize regions of the Earth's ecosystems mainly according to the structure and composition of vegetation. Different researchers have applied different methods to define continental boundaries of biomes dominated by different functional types of vegetative communities that are limited in distribution by climate, precipitation, weather and other environmental variables. Examples of biome names include: tropical rainforest, temperate broadleaf and mixed forests, temperate deciduous forest, taiga, tundra, hot desert, and polar desert. Other researchers have recently started to categorize other types of biomes, such as the human and oceanic microbiomes. To a microbe, the human body is a habitat and a landscape. The microbiome has been largely discovered through advances in molecular genetics that have revealed a hidden richness of microbial diversity on the planet. The oceanic microbiome plays a significant role in the ecological biogeochemistry of the planet's oceans.

Biosphere

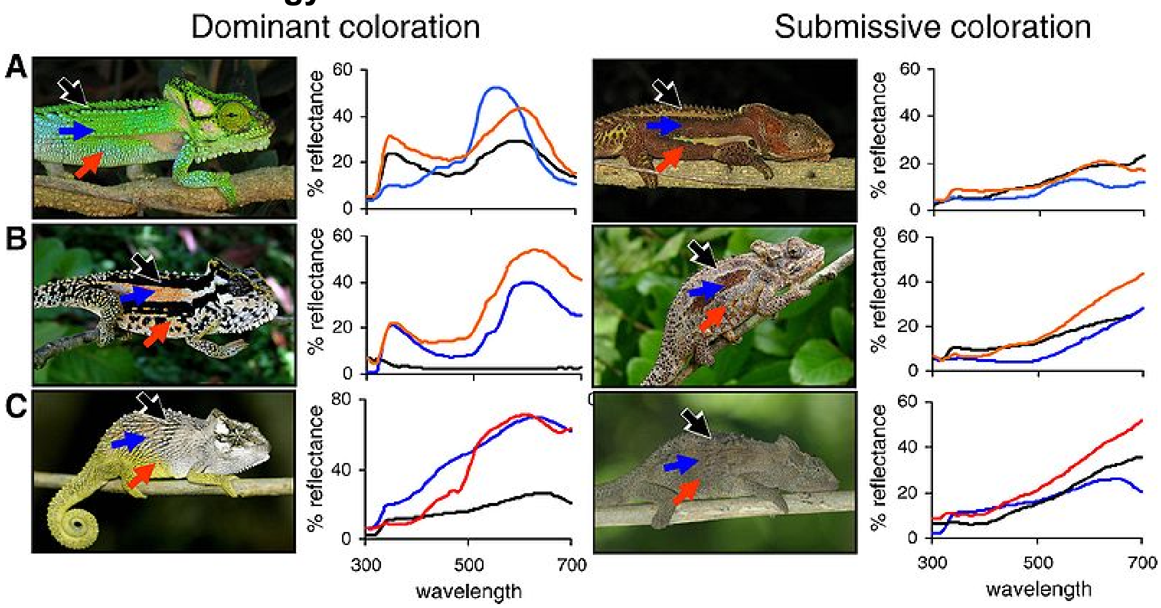
Ecological theory has been used to explain self-emergent regulatory phenomena at the planetary scale. The largest scale of ecological organization is the biosphere: the total sum of ecosystems on the planet. Ecological relations regulate the flux of energy, nutrients, and climate all the way up to the planetary scale. For example, the dynamic history of the planetary CO_2 and O_2 composition of the atmosphere has been largely determined by the biogenic flux of gases coming from respiration and photosynthesis, with levels fluctuating over time and in relation to the ecology and evolution of plants and animals. When sub-component parts are organized into a whole there are oftentimes emergent properties that describe the nature of the system. This the Gaia hypothesis, and is an example of holism applied in ecological theory. The ecology of the planet acts as a single regulatory or holistic unit called Gaia. The Gaia hypothesis states that there is an emergent feedback loop generated by the metabolism of living organisms that maintains the temperature of the Earth and atmospheric conditions within a narrow self-regulating range of tolerance.

Relation to evolution

Ecology and evolution are considered sister disciplines of the life sciences. Natural selection, life history, development, adaptation, populations, and inheritance are examples of concepts that thread equally into ecological and evolutionary theory. Morphological, behavioral and/or genetic traits, for example, can be mapped onto evolutionary trees to study the historical development of a species in relation to their functions and roles in different ecological circumstances. In this framework, the analytical tools of ecologists and evolutionists overlap as they organize, classify and investigate life through common systematic principals, such as phylogenetics or the

Linnaean system of taxonomy. The two disciplines often appear together, such as in the title of the journal *Trends in Ecology and Evolution*. There is no sharp boundary separating ecology from evolution and they differ more in their areas of applied focus. Both disciplines discover and explain emergent and unique properties and processes operating across different spatial or temporal scales of organization. While the boundary between ecology and evolution is not always clear, it is understood that ecologists study the abiotic and biotic factors that influence the evolutionary process.

Behavioral ecology



Social display and color variation in differently adapted species of chameleons (*Bradypodion* spp.). Chameleons change their skin color to match their background as a behavioral defense mechanism and also use color to communicate with other members of their species, such as dominant (left) versus submissive (right) patterns shown in the three species (A-C) above.

All organisms are motile to some extent. Even plants express complex behavior, including memory and communication. Behavioral ecology is the study of ethology and its ecological and evolutionary implications. Ethology is the study of observable movement or behavior in nature. This could include investigations of motile sperm of plants, mobile phytoplankton, zooplankton swimming toward the female egg, the cultivation of fungi by weevils, the mating dance of a salamander, or social gatherings of amoeba.

Adaptation is the central unifying concept in behavioral ecology."International Society for Behavioral Ecology". Behaviors can be recorded as traits and inherited in much the same way that eye and hair color can. Behaviors evolve and become adapted to the ecosystem because they are subject to the forces of natural selection. Hence, behaviors can be adaptive, meaning that they evolve functional utilities that increases reproductive success for the individuals that inherit such traits. This is also the technical definition for fitness in biology, which is a measure of reproductive success over successive generations.

Predator-prey interactions are an introductory concept into food-web studies as well as behavioral ecology. Prey species can exhibit different kinds of behavioral adaptations to predators, such as avoid, flee or defend. Many prey species are faced with multiple predators that differ in the degree of danger posed. To be adapted to their environment and face predatory threats, organisms must balance their energy budgets as they invest in different aspects of their life history, such as growth, feeding, mating, socializing, or modifying their habitat. Hypotheses posited in behavioral ecology are generally based on adaptive principals of conservation, optimization or efficiency. For example,

"The threat-sensitive predator avoidance hypothesis predicts that prey should assess the degree of threat posed by different predators and match their behavior according to current levels of risk."

"The optimal flight initiation distance occurs where expected postencounter fitness is maximized, which depends on the prey's initial fitness, benefits obtainable by not fleeing, energetic escape costs, and expected fitness loss due to predation risk."

Symbiosis: Leafhoppers (*Eurymela fenestrata*) are protected by ants (*Iridomyrmex purpureus*) in a symbiotic relationship. The ants protect the leafhoppers from predators and in return the leafhoppers feeding on plants exude honeydew from their anus that provides energy and nutrients to tending ants.

Elaborate sexual displays and posturing are encountered in the behavioral ecology of animals. The birds of paradise, for example, display elaborate ornaments and song during courtship. These displays serve a dual purpose of signaling healthy or well-adapted individuals and desirable genes. The elaborate displays are driven by sexual selection as an advertisement of quality of traits among male suitors.

Social ecology

Social ecological behaviors are notable in the social insects, slime moulds, social spiders, human society, and naked mole rats where eusocialism has evolved. Social behaviors include reciprocally beneficial behaviors among kin and nest mates. Social behaviors evolve from kin and group selection. Kin selection explains altruism through genetic relationships, whereby an altruistic behavior leading to death is rewarded by the survival of genetic copies distributed among surviving relatives. The social insects, including ants, bees and wasps are most famously studied for this type of relationship because the male drones are clones that share the same genetic make-up as every other male in the colony. In contrast, group selectionists find examples of altruism among non-genetic relatives and explain this through selection acting on the group, whereby it becomes selectively advantageous for groups if their members express altruistic behaviors to one another. Groups that are predominantly altruists beat groups that are predominantly selfish.

Coevolution

Ecological interactions can be divided into host and associate relationships. A host is any entity that harbors another that is called the associate. Host and associate relationships among species that are mutually or reciprocally beneficial are called mutualisms. If the host and associate are physically connected, the relationship is called symbiosis. Approximately 60% of all plants, for example, have a symbiotic relationship with arbuscular mycorrhizal fungi. Symbiotic plants and fungi exchange carbohydrates for mineral nutrients. Symbiosis differs from indirect mutualisms where the organisms live apart. For example, tropical rainforests regulate the Earth's atmosphere. Trees living in the equatorial regions of the planet supply oxygen into the atmosphere that sustains species living in distant polar regions of the planet. This relationship is called commensalism because many other host species receive the benefits of clean air at no cost or harm to the associate tree species supplying the oxygen. The host and associate relationship is called parasitism if one species benefits while the other suffers. Competition among species or among members of the same species is defined as reciprocal antagonism, such as grasses competing for growth space.

Parasites: A harvestman arachnid is parasitized by mites. This is parasitism because the harvestman is being consumed as its juices are slowly sucked out while the mites gain all the benefits traveling on and feeding off of their host.

Popular ecological study systems for mutualism include, fungus-growing ants employing agricultural symbiosis, bacteria living in the guts of insects and other organisms, the fig wasp and yucca moth pollination complex, lichens with fungi and photosynthetic algae, and corals with photosynthetic algae.. Nevertheless, many organisms exploit host rewards without reciprocating and thus have been branded with a myriad of not-very-flattering names such as 'cheaters', 'exploiters', 'robbers', and 'thieves'. Although cheaters impose several host cots (e.g., via damage to their reproductive organs or propagules, denying the services of a beneficial partner), their net effect on host fitness is not necessarily negative and, thus, becomes difficult to forecast.

Biogeography

The word *biogeography* is an amalgamation of *biology* and *geography*. Biogeography is the comparative study of the geographic distribution of organisms and the corresponding evolution of their traits in space and time. The Journal of Biogeography was established in 1974. Biogeography and ecology share many of their disciplinary roots. For example, the theory of island biogeography, published by the mathematician Robert MacArthur and ecologist Edward O. Wilson in 1967 is considered one of the fundamentals of ecological theory.

Biogeography has a long history in the natural sciences where questions arise concerning the spatial distribution of plants and animals. Ecology and evolution provide the explanatory context for biogeographical studies. Biogeographical patterns result from ecological processes that influence range distributions, such as migration and dispersal. and from historical processes that split populations or species into different areas. The biogeographic processes that result in the natural splitting of species explains much of the modern distribution of the Earth's biota. The splitting of lineages in a species is called vicariance biogeography and it is a sub-discipline of biogeography. There are also practical applications in the field of biogeography concerning ecological systems and processes. For example, the range and distribution of biodiversity and invasive species responding to climate change is a serious concern and active area of research in context of global warming.

r/K-Selection theory

A population ecology concept (introduced in MacArthur and Wilson's (1967) book, *The Theory of Island Biogeography*) is r/K selection theory, one of the first predictive models in ecology used to explain life-history evolution. The premise behind the r/K selection model is that natural selection pressures change according to population density. For example, when an island is first colonized, density of individuals is low. The initial increase in population size is *not* limited by competition, leaving an abundance of available resources for rapid population growth. These early phases of population growth experience *density-independent* forces of natural selection, which is called *r*-selection. As the population becomes more crowded, it approaches the island's carrying capacity, thus forcing individuals to compete more heavily for fewer available resources. Under crowded conditions the population experiences density-dependent forces of natural selection, called *K*-selection.

In the *r/K*-selection model, the first variable *r* is the intrinsic rate of natural increase in population size and the second variable *K* is the carrying capacity of a population. Different species evolve different life-history strategies spanning a continuum between these two selective forces. An *r*-selected species is one that has high birth rates, low levels of parental investment, and high rates of mortality before individuals reach maturity. Evolution favors high rates of fecundity in *r*-selected species. Many kinds of insects and invasive species exhibit *r*-selected characteristics. In contrast, a *K*-selected species has low rates of fecundity, high levels of parental investment in the young, and low rates of mortality as individuals mature. Humans and elephants are examples of species exhibiting *K*-selected characteristics, including longevity and efficiency in the conversion of more resources into fewer offspring.

Molecular ecology

The important relationship between ecology and genetic inheritance predates modern techniques for molecular analysis. Molecular ecological research became more feasible with the development of rapid and accessible genetic technologies, such as the polymerase chain reaction (PCR). The rise of molecular technologies and influx of research questions into this new ecological field resulted in the publication *Molecular Ecology* in 1992. Molecular ecology uses various analytical techniques to study genes in an evolutionary and ecological context. In 1994, John Avise also played a leading role in this area of science with the publication of his book, *Molecular Markers, Natural History and Evolution*. Newer technologies opened a wave of genetic analysis into organisms once difficult to study from an ecological or evolutionary standpoint, such as bacteria, fungi and nematodes.

Molecular ecology engendered a new research paradigm to investigate ecological questions considered otherwise intractable. Molecular investigations revealed previously obscured details in the tiny intricacies of nature and improved resolution into probing questions about behavioral and biogeographical ecology. For example, molecular ecology revealed promiscuous sexual behavior and multiple male partners in tree swallows previously thought to be socially monogamous. In a biogeographical context, the marriage between genetics, ecology and evolution resulted in a new sub-discipline called phylogeography.

Relation to the environment

The environment is dynamically interlinked, imposed upon and constrains organisms at any time throughout their life cycle. Like the term ecology, environment has different conceptual meanings and to many these terms also overlap with the concept of *nature*. Environment "...includes the physical world, the social world of human relations and the built world of human creation."[:62] The environment in ecosystems includes both physical parameters and biotic attributes. The physical environment is external to the level of biological organization under investigation, including abiotic factors such as temperature, radiation, light, chemistry, climate and geology. The biotic environment includes genes, cells, organisms, members of the same species (conspecifics) and other species that share a habitat. The laws of thermodynamics applies to ecology by means of its physical state. Armed with an understanding of metabolic and thermodynamic principles a complete accounting of energy and material flow can be traced through an ecosystem.

Environmental and ecological relations are studied through reference to conceptually manageable and isolated parts. Once the effective environmental components are understood they conceptually link back together as a *holocoenotic* system. In other words, the organism and the environment form a dynamic whole (or umwelt).[:252] Change in one ecological or environmental factor can concurrently affect the dynamic state of an entire ecosystem.

Ecological studies are necessarily holistic as opposed to reductionistic. Holism has three scientific meanings or uses that identify with: 1) the mechanistic complexity of ecosystems, 2) the practical description of patterns in quantitative reductionist terms where correlations may be identified but nothing is understood about the causal relations without reference to the whole system, which leads to 3) a metaphysical hierarchy whereby the causal relations of larger systems are understood without reference to the smaller parts. An example of the metaphysical aspect to holism is the trend of increased exterior thickness in shells of different species. The reason for a thickness increase can be understood through reference to principals of natural selection via predation without any reference to the biomolecular properties of the exterior shells.

Metabolism and the early atmosphere

> Metabolism – the rate at which energy and material resources are taken up from the environment, transformed within an organism, and allocated to maintenance, growth and reproduction – is a fundamental physiological trait.
>
> Ernst et al.[:991]

The Earth formed approximately 4.5 billion years ago and environmental conditions were too extreme for life to form for the first 500 million years. During this early Hadean period, the Earth started to cool, allowing a crust and oceans to form. Environmental conditions were unsuitable for the origins of life for the first billion years after the Earth formed. The Earth's atmosphere transformed from being dominated by hydrogen, to one composed mostly of methane and ammonia. Over the next billion years the metabolic activity of life transformed the atmosphere to higher concentrations of carbon dioxide, nitrogen, and water vapor. These gases changed the way that light from the sun hit the Earth's surface and greenhouse effects trapped heat. There were untapped sources of free energy within the mixture of reducing and oxidizing gasses that set the stage for primitive ecosystems to evolve and, in turn, the atmosphere also evolved.

The leaf is the primary site of photosynthesis in most plants.

Throughout history, the Earth's atmosphere and biogeochemical cycles have been in a dynamic equilibrium with planetary ecosystems. The history is characterized by periods of significant transformation followed by millions of years of stability. The evolution of the earliest organisms, likely anaerobic methanogen microbes, started the process by converting atmospheric hydrogen into methane ($4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$). Anoxygenic photosynthesis converting hydrogen sulfide into other sulfur compounds or water ($2H_2S + CO_2 \rightarrow h\nu \rightarrow CH_2O \rightarrow H_2O \rightarrow + 2S$ or $2H_2 + CO_2 + h\nu \rightarrow CH_2O + H_2O$), as occurs in deep sea hydrothermal vents today, reduced hydrogen concentrations and increased atmospheric methane. Early forms of fermentation also increased levels of atmospheric methane. The transition to an oxygen dominant atmosphere (the *Great Oxidation*) did not begin until approximately 2.4-2.3 billion years ago, but photosynthetic processes started 0.3 to 1 billion years prior.

Radiation: heat, temperature and light

The biology of life operates within a certain range of temperatures. Heat is a form of energy that regulates temperature. Heat affects growth rates, activity, behavior and primary production. Temperature is largely dependent on the incidence of solar radiation. The latitudinal and longitudinal spatial variation of temperature greatly affects climates and consequently the distribution of biodiversity and levels of primary production in different ecosystems or biomes across the planet. Heat and temperature relate importantly to metabolic activity. Poikilotherms, for example, have a body temperature that is largely regulated and dependent on the temperature of the external environment. In contrast, homeotherms regulate their internal body temperature by expending metabolic energy.

There is a relationship between light, primary production, and ecological energy budgets. Sunlight is the primary input of energy into the planet's ecosystems. Light is composed of electromagnetic energy of different wavelengths. Radiant energy from the sun generates heat, provides photons of light measured as active energy in the chemical reactions of life, and also acts as a catalyst for genetic mutation. Plants, algae, and some bacteria absorb light and assimilate the energy through photosynthesis. Organisms capable of assimilating energy by photosynthesis or through inorganic fixation of H_2S are autotrophs. Autotrophs—responsible for primary production—assimilate light energy that becomes metabolically stored as potential energy in the form of biochemical enthalpic bonds.

Physical environments

Water

Wetland conditions such as shallow water, high plant productivity, and anaerobic substrates provide a suitable environment for important physical, biological, and chemical processes. Because of these processes, wetlands play a vital role in global nutrient and element cycles.[:29]

The rate of diffusion of carbon dioxide and oxygen is approximately 10,000 times slower in water than it is in air. When soils become flooded, they quickly lose oxygen and transform into a low-concentration (hypoxic -with less than 2 mg O_2l^{-1}) environment and eventually become completely (anoxic) environment where anaerobic bacteria thrive among the roots. Water also influences the spectral composition and amount of light as it reflects off the water surface and submerged particles. Aquatic plants exhibit a wide variety of morphological and physiological adaptations that allow them to survive, compete and diversify these environments. For example, the roots and stems develop large air spaces (Aerenchyma) that regulate the efficient transportation gases (for example, CO_2 and O_2) used in respiration and photosynthesis. In drained soil, microorganisms use oxygen during respiration. In aquatic environments, anaerobic soil microorganisms use nitrate, manganese ions, ferric ions, sulfate, carbon dioxide and some organic compounds. The activity of soil microorganisms and the chemistry of the water reduces the oxidation-reduction potentials of the water. Carbon dioxide, for example, is reduced to methane (CH_4) by methanogenic bacteria. Salt water plants (or halophytes) have specialized physiological adaptations, such as the development of special organs for shedding salt and osmo-regulate their internal salt (NaCl) concentrations, to live in estuarine, brackish, or oceanic environments. The physiology of fish is also specially adapted to deal with high levels of salt through osmoregulation. Their gills form electrochemical gradients that mediate salt excresion in saline environments and uptake in fresh water.

Gravity

The shape and energy of the land is affected to a large degree by gravitational forces. On a larger scale, the distribution of gravitational forces on the earth are uneven and influence the shape and movement of tectonic plates as well as having an influence on geomorphic processes such as orogeny and erosion. These forces govern many of the geophysical properties and distributions of ecological biomes across the Earth. On a organism scale, gravitational forces provide directional cues for plant and fungal growth (gravitropism), orientation cues for animal migrations, and influence the biomechanics and size of animals. Ecological traits, such as allocation of biomass in trees during growth are subject to mechanical failure as gravitational forces influence the position and structure of branches and leaves. The cardiovascular systems of all animals are functionally adapted to overcome pressure and gravitational forces that change according to the features of organisms (e.g., height, size, shape), their behavior (e.g., diving, running, flying), and the habitat occupied (e.g., water, hot deserts, cold tundra).

Pressure

Climatic and osmotic pressure places physiological constraints on organisms, such as flight and respiration at high altitudes, or diving to deep ocean depths. These constraints influence vertical limits of ecosystems in the biosphere as organisms are physiologically sensitive and adapted to atmospheric and osmotic water pressure differences. Oxygen levels, for example, decrease with increasing pressure and are a limiting factor for life at higher altitudes. Water transportation through trees is another important ecophysiological parameter where osmotic pressure gradients factor in. Water pressure in the depths of oceans requires that organisms adapt to these conditions. For example, mammals, such as whales, dolphins and seals are specially adapted to deal with changes in sound due to water pressure differences. Different species of hagfish provide another example of adaptation to deep-sea pressure through specialized protein adaptations.

Wind and turbulence

The architecture of inflorescence in grasses is subject to the physical pressures of wind and shaped by the forces of natural selection facilitating wind-pollination (or anemophily).

Turbulent forces in air and water have significant effects on the environment and ecosystem distribution, form and dynamics. On a planetary scale, ecosystems are affected by circulation patterns in the global trade winds. Wind power and the turbulent forces it creates can influence heat, nutrient, and biochemical profiles of ecosystems. For example, wind running over the surface of a lake creates turbulence, mixing the water column and influencing the environmental profile to create thermally layered zones, partially governing how fish, algae, and other parts of the aquatic ecology are structured. Wind speed and turbulence also exert influence on rates of evapotranspiration rates and energy budgets in plants and animals. Wind speed, temperature and moisture content can vary as winds travel across different landfeatures and elevations. The westerlies, for example, come into contact with the coastal and interior mountains of western North America to produce a rain shadow on the leeward side of the mountain. The air expands and moisture condenses as the winds move up in elevation which can cause precipitation; this is called orographic lift. This environmental process produces spatial divisions in biodiversity, as species adapted to wetter conditions are range-restricted to the coastal mountain valleys and unable to migrate across the xeric ecosystems of the Columbia Basin to intermix with sister lineages that are segregated to the interior mountain systems.

Fire

Forest fires modify the land by leaving behind an environmental mosaic that diversifies the landscape into different seral stages and habitats of varied quality (left). Some species are adapted to forest fires, such as pine trees that open their cones only after fire exposure (right).

Plants convert carbon dioxide into biomass and emit oxygen into the atmosphere. Approximately 350 million years ago (near the Devonian period) the photosynthetic process brought the concentration of atmospheric oxygen above 17%, which allowed combustion to occur. Fire releases CO_2 and converts fuel into ash and tar. Fire is a significant ecological parameter that raises many issues pertaining to its control and suppression in management. While the issue of fire in relation to ecology and plants has been recognized for a long time, Charles Cooper brought attention to the issue of forest fires in relation to the ecology of forest fire suppression and management in the 1960s.

Fire creates environmental mosaics and a patchiness to ecosystem age and canopy structure. Native North Americans were among the first to influence fire regimes by controlling their spread near their homes or by lighting fires to stimulate the production of herbaceous foods and basketry materials. The altered state of soil nutrient supply and cleared canopy structure also opens new ecological niches for seedling establishment. Most ecosystem are adapted to natural fire cycles. Plants, for example, are equipped with a variety of adaptations to deal with forest fires. Some species (e.g., *Pinus halepensis*) cannot germinate until after their seeds have lived through a fire. This environmental trigger for seedlings is called serotiny. Some compounds from smoke also promote seed germination. Fire plays a major role in the persistence and resilience of ecosystems.

Biogeochemistry

Ecologists study and measure nutrient budgets to understand how these materials are regulated and flow through the environment. This research has led to an understanding that there is a global feedback between ecosystems and the physical parameters of this planet including minerals, soil, pH, ions, water and atmospheric gases. There are six major elements, including H (hydrogen), C (carbon), N (nitrogen), O (oxygen), S (sulfur), and P (phosphorus) that form the constitution of all biological macromolecules and feed into the Earth's geochemical processes. From the smallest scale of biology the combined effect of billions upon billions of ecological processes amplify and ultimately regulate the biogeochemical cycles of the Earth. Understanding the relations and cycles mediated between these elements and their ecological pathways has significant bearing toward understanding global biogeochemistry.

The ecology of global carbon budgets gives one example of the linkage between biodiversity and biogeochemistry. For starters, the Earth's oceans are estimated to hold 40,000 gigatonnes (Gt) carbon, vegetation and soil is estimated to hold 2070 Gt carbon, and fossil fuel emissions are estimated to emit an annual flux of 6.3 Gt carbon. At different times in the Earth's history there has been major restructuring in these global carbon budgets that was regulated to a large extent by the ecology of the land. For example, through the early-mid Eocene volcanic outgassing, the oxidation of methane stored in wetlands, and seafloor gases increased atmospheric CO_2 concentrations to levels as high as 3500 ppm. In the Oligocene, from 25 to 32 million years ago, there was another significant restructuring in the global carbon cycle as grasses evolved a special type of C4 photosynthesis and expanded their ranges. This new photosynthetic pathway evolved in response to the drop in atmospheric CO_2 concentrations below 550 ppm.

These kinds of ecosystem functions feed back significantly into global atmospheric models for carbon cycling. Loss in the abundance and distribution of biodiversity causes global carbon cycle feedbacks that are expected to increase rates of global warming in the next century. The effect of global warming melting large sections of permafrost creates a new mosaic of flooded areas where decomposition results in the emission of methane (CH_4). Hence, there is a relationship between global warming, decomposition and respiration in soils and wetlands producing significant climate feedbacks and altered global biogeochemical cycles. There is concern over increases in atmospheric methane in the context of the global carbon cycle, because methane is also a greenhouse gas that is 23 times more effective at absorbing long-wave radiation than CO_2 on a 100 year time scale.

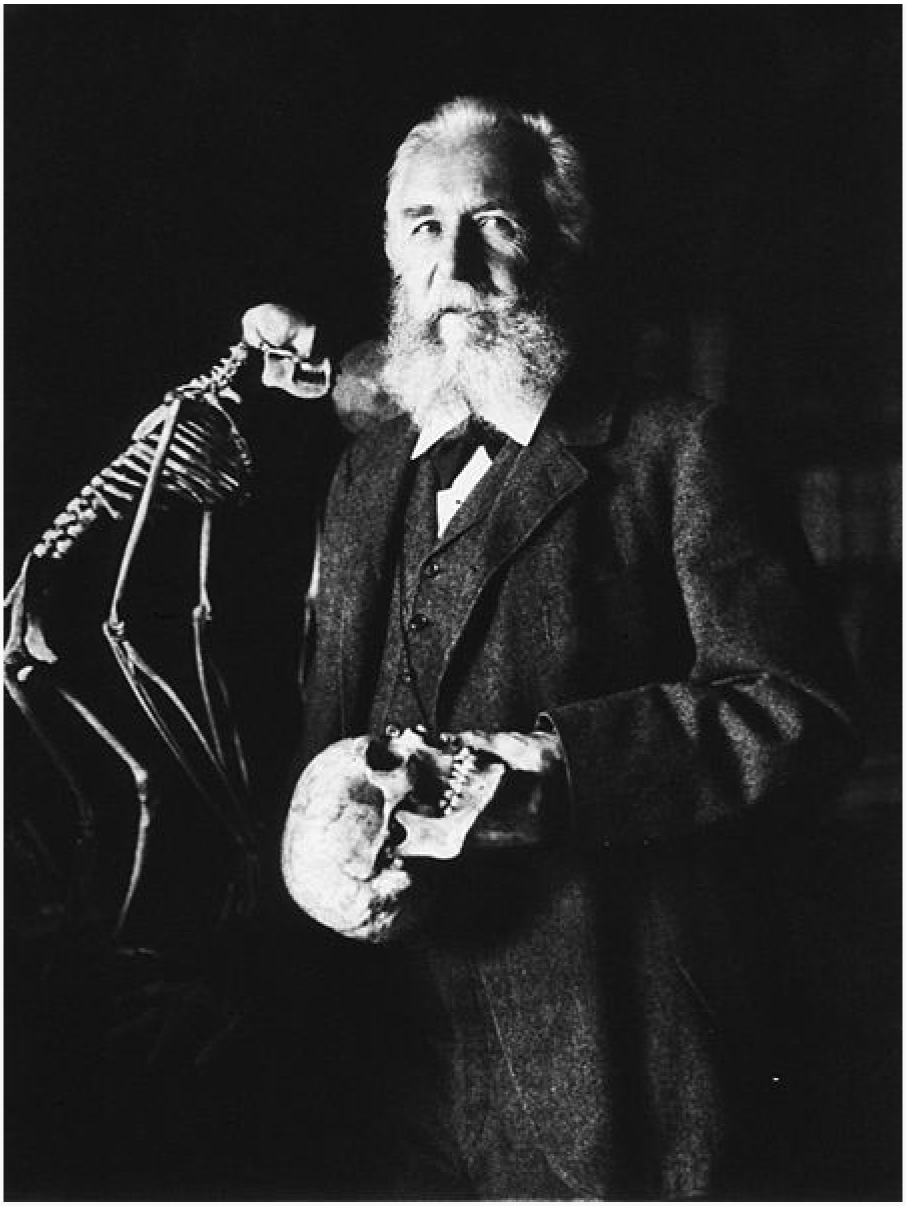
History

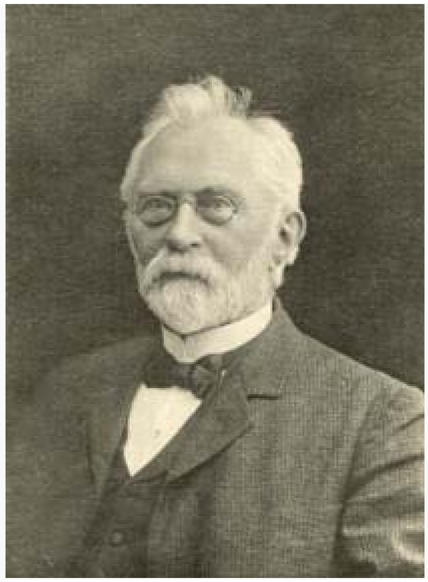
Early beginnings

Ecology has a complex origin due in large part to its interdisciplinary nature. Ancient philosophers of Greece, including Hippocrates and Aristotle were among the first to record their observations on natural history. However, philosophers in ancient Greece viewed life as a static element that did not require an understanding of adaptation, a modern cornerstone of ecological theory. Topics more familiar in the modern context, including food chains, population regulation, and productivity, did not develop until the 1700s through the published works of microscopist Antoni van Leeuwenhoek (1632–1723) and botanist Richard Bradley(1688?-1732). Biogeographer Alexander von Humbolt (1769–1859) was another early pioneer in ecological thinking and was among the first to recognize ecological gradients. Humbolt alluded to the modern ecological law of species to area relationships.

In the early 20th century, ecology was an analytical form of natural history. Following in the traditions of Aristotle, the descriptive nature of natural history examined the interaction of organisms with both their environment and their community. Natural historians, including James Hutton and Jean-Baptiste Lamarck, contributed significant works that laid the foundations of the modern ecological sciences. The term "ecology" (German: *Oekologie*) is of a more recent origin and was first coined by the German biologist Ernst Haeckel in his book *Generelle Morphologie der Organismen* (1866).

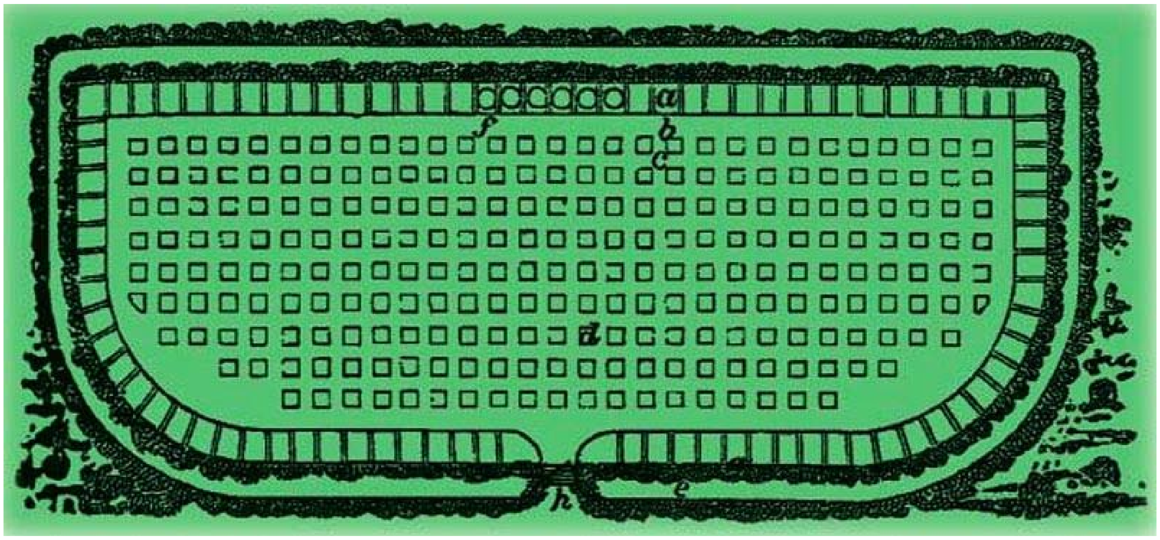
> By ecology we mean the body of knowledge concerning the economy of nature-the investigation of the total relations of the animal both to its inorganic and its organic environment; including, above all, its friendly and inimical relations with those animals and plants with which it comes directly or indirectly into contact-in a word, ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle of existence.
>
> Haeckel's definition quoted in Esbjorn-Hargens[:6]


Ernst Haeckel (above) and Eugenius Warming (below), two founders of ecology



Opinions differ on who was the founder of modern ecological theory. Some mark Haeckel's definition as the beginning, others say it was Eugenius Warming with the writing of Oecology of Plants: An Introduction to the Study of Plant Communities (1895). Ecology may also be thought to have begun with Carl Linnaeus' research principals on the economy of nature that matured in the early 18th century. He founded an early branch of ecological study he called the economy of nature. The works of Linnaeus influenced Darwin in *The Origin of Species* where he adopted the usage of Linnaeus' phrase on the *economy or polity of nature*. Linnaeus was the first to frame *the balance of nature* as a testable hypothesis. Haeckel, who admired Darwin's work, defined ecology in reference to the economy of nature which has led some to question if ecology is synonymous with Linnaeus' concepts for the economy of nature.

The modern synthesis of ecology is a young science, which first attracted substantial formal attention at the end of the 19th century (around the same time as evolutionary studies) and become even more popular during the 1960s environmental movement, though many observations, interpretations and discoveries relating to ecology extend back to much earlier studies in natural history. For example, the concept on the balance or regulation of nature can be traced back to Herodotos (died *c*. 425 BC) who described an early account of mutualism along the Nile river where crocodiles open their mouths to beneficially allow sandpipers safe access to remove leeches. In the broader contributions to the historical development of the ecological sciences, Aristotle is considered one of the earliest naturalists who had an influential role in the philosophical development of ecological sciences. One of Aristotle's students, Theophrastus, made astute ecological observations about plants and posited a philosophical stance about the autonomous relations between plants and their environment that is more in line with modern ecological thought. Both Aristotle and Theophrastus made extensive observations on plant and animal migrations, biogeography, physiology, and their habits in what might be considered an analog of the modern ecological niche. Hippocrates, another Greek philosopher, is also credited with reference to ecological topics in its earliest developments.



The layout of the first ecological experiment, noted by Charles Darwin in *The Origin of Species*, was studied in a grass garden at Woburn Abbey in 1817. The experiment studied the performance of different mixtures of species planted in different kinds of soils.

From Aristotle to Darwin the natural world was predominantly considered static and unchanged since its original creation. Prior to *The Origin of Species* there was little appreciation or understanding of the dynamic and reciprocal relations between organisms, their adaptations and their modifications to the environment. While Charles Darwin is most notable for his treatise on evolution, he is also one of the founders of soil ecology. In *The Origin of Species* Darwin also made note of the first ecological experiment that was published in 1816. In the science leading up to Darwin the notion of evolving species was gaining popular support. This scientific paradigm changed the way that researchers approached the ecological sciences.

> Nowhere can one see more clearly illustrated what may be called the sensibility of such an organic complex,--expressed by the fact that whatever affects any species belonging to it, must speedily have its influence of some sort upon the whole assemblage. He will thus be made to see the impossibility of studying any form completely, out of relation to the other forms,--the necessity for taking a comprehensive survey of the whole as a condition to a satisfactory understanding of any part.
>
> Stephen Forbes (1887)

After the turn of 20th century

Some suggest that the first ecological text (*Natural History of Selborne*) was published in 1789, by Gilbert White (1720–1793). The first American ecology book was published in 1905 by Frederic Clements. In his book, Clements forwarded the idea of plant communities as a superorganism. This publication launched a debate between ecological holism and individualism that lasted until the 1970s. The Clements superorganism concept proposed that ecosystems progress through regular and determined stages of seral development that are analogous to developmental stages of an organism whose parts function to maintain the integrity of the whole. The Clementsian paradigm was challenged by Henry Gleason. According to Gleason, ecological communities develop from the unique and coincidental association of individual organisms. This perceptual shift placed the focus back onto the life histories of individual organisms and how this relates to the development of community associations.

The Clementsian superorganism theory has not been completely rejected, but some suggest it was an overextended application of holism. Holism remains a critical part of the theoretical foundation in contemporary ecological studies. Holism was first introduced in 1926 by a polarizing historical figure, a South African General named Jan Christian Smuts. Smuts was inspired by Clement's superorganism theory as he developed and published on the concept of holism, which contrasts starkly against his racial political views as the father of apartheid. Around the same time, Charles Elton pioneered the concept of food chains in his classical book "Animal Ecology". Elton defined ecological relations using concepts of food chains, food cycles, food size, and described numerical relations among different functional groups and their relative abundance. Elton's 'food cycle' was replaced by 'food web' in a subsequent ecological text.

Ecology has developers in many nations, including Russia's Vladimir Vernadsky and his founding of the biosphere concept in the 1920s or Japan's Kinji Imanishi and his concepts of harmony in nature and habitat segregation in the 1950s. The scientific recognition or importance of contributions to ecology from other cultures is hampered by language and translation barriers.

Ecosystem services

A bumblebee pollinating a flower, one example of an ecosystem service

The ecosystems of planet Earth are coupled to human environments. Ecosystems regulate the global geophysical cycles of energy, climate, soil nutrients, and water that in turn support and grow natural capital (including the environmental, physiological, cognitive, cultural, and spiritual dimensions of life). Ultimately, every manufactured product in human environments comes from natural systems. Ecosystems are considered common-pool resources because ecosystems do not exclude beneficiaries and they can be depleted or degraded. For example, green space within communities provides sustainable health services that reduces mortality and regulates the spread of vector borne disease. Research shows that people who are more engaged with regular access to natural areas have lower rates of diabetes, heart disease and psychological disorders. These ecological health services are regularly depleted through urban development projects that do not factor in the common-pool value of ecosystems.

The ecological commons delivers a diverse supply of community services that sustains the well-being of human society. The Millennium Ecosystem Assessment, an international UN initiative involving more than 1,360 experts worldwide, identifies four main ecosystem service types having 30 sub-categories stemming from natural capital. The ecological commons includes provisioning (e.g., food, raw materials, medicine, water supplies), regulating (e.g., climate, water, soil retention, flood retention), cultural (e.g., science and education, artistic, spiritual), and supporting (e.g., soil formation, nutrient cycling, water cycling) services.

Policy and human institutions should rarely assume that human enterprise is benign. A safer assumption holds that human enterprise almost always exacts an ecological toll - a debit taken from the ecological commons.[:95]

Sixth mass extinction

Global assessments of biodiversity indicate that the current epoch, the Holocene (or Anthropocene) is a sixth mass extinction. Species loss is accelerating at 100–1000 times faster than average background rates in the fossil record. The field of conservation biology involves ecologists that are researching, confronting, and searching for solutions to sustain the planet's ecosystems for future generations.

"Human activities are associated directly or indirectly with nearly every aspect of the current extinction spasm."[:]

Nature is a resilient system. Ecosystems regenerate, withstand, and are forever adapting to fluctuating environments. Ecological resilience is an important conceptual framework in conservation management and it is defined as the preservation of biological relations in ecosystems that persevere and regenerate in response to disturbance over time. Disturbances, such as fire, are both cause and product of natural fluctuations in death rates, species assemblages, and biomass densities within an ecological community. These disturbances create places of renewal where new directions emerge out of the patchwork of natural experimentation and opportunity. However, persistent, systematic, large and nonrandom disturbance caused by the niche constructing behavior of human beings, habitat conversion and land development, has pushed many of the Earth's ecosystems to the extent of their resilient thresholds. Three planetary thresholds have already been crossed, including 1) biodiversity loss, 2) climate change, and 3) nitrogen cycles. These biophysical systems are ecologically interrelated and naturally resilient, but human civilization has transitioned the planet to the Anthropocene epoch, where the threshold for planetary scale resilience has been crossed and the ecological state of the Earth is deteriorating rapidly to the detriment of humanity. The world's fisheries and oceans, for example, are facing dire challenges as the threat of global collapse appears imminent, with serious ramifications for the well-being of humanity. The ecology of the planet is further threatened by global warming, but investments in nature conservation can provide a regulatory feedback to store and regulate carbon and other greenhouse gases.

Ecological footprint

> While we are used to thinking of cities as geographically discrete places, most of the land "occupied" by their residents lies far beyond their borders. The total area of land required to sustain an urban region (its "ecological footprint") is typically at least an order of magnitude greater than that contained within municipal boundaries or the associated built-up area.[:121]

In 1992, William Rees developed the ecological footprint concept. The ecological footprint and its close analog the water footprint has become a popular way of accounting for the level of impact that human society is imparting on the Earth's ecosystems. All indications are that the human enterprise is unsustainable as the footprint of society is placing too much stress on the ecology of the planet. The WWF 2008 living planet report and other researchers report that human civilization has exceeded the bio-regenerative capacity of the planet. This means that the footprint of human consumption is extracting more natural resources than can be replenished by ecosystems around the world.

Ecological economics

Ecological economics is an economic science that extends its methods of valuation onto nature in an effort to address the inequity between market growth and biodiversity loss. Natural capital is the stock of materials or information stored in biodiversity that generates services that can enhance the welfare of communities. Population losses are the more sensitive indicator of natural capital than are species extinction in the accounting of ecosystem services. The prospect for recovery in the economic crisis of nature is grim. Populations, such as local ponds and patches of forest are being cleared away and lost at rates that exceed species extinctions. The mainstream growth-based economic system adopted by governments worldwide does not include a price or markets for natural capital. This type of economic system places further ecological debt onto future generations.

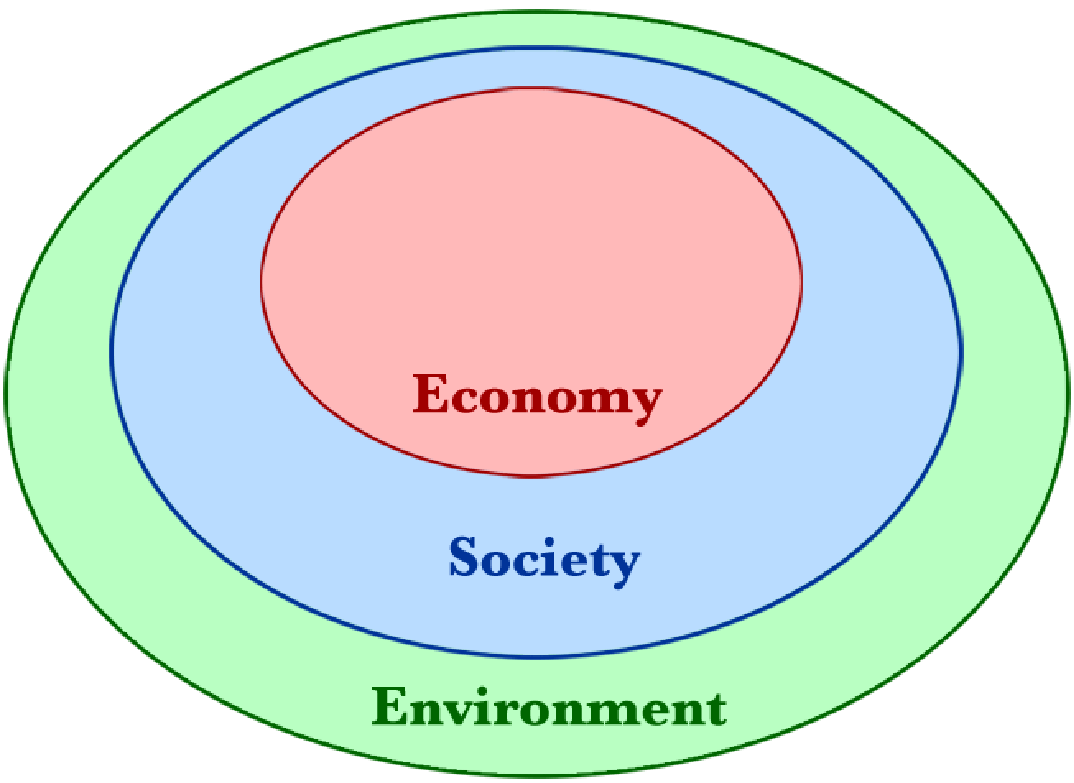
> Many human-nature interactions occur indirectly due to the production and use of human-made (manufactured and synthesized) products, such as electronic appliances, furniture, plastics, airplanes, and automobiles. These products insulate humans from the natural environment, leading them to perceive less dependence on natural systems than is the case, but all manufactured products ultimately come from natural systems.[:640]

Human societies are increasingly being placed under stress as the ecological commons is diminished through an accounting system that has incorrectly assumed "... that nature is a fixed, indestructible capital asset."[:] The current wave of threats, including massive extinction rates and concurrent loss of natural capital to the detriment of human society, is happening rapidly. This is called a biodiversity crisis, because 50% of the worlds species are predicted to go extinct within the next 50 years. Conventional monetary analyses are unable to detect or deal with these sorts of ecological problems. Multiple global ecological economic initiatives are being promoted to solve this problem. For example, governments of the G8 met in 2007 and set forth The Economics of Ecosystems and Biodiversity (TEEB) initiative:

In a global study we will initiate the process of analyzing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation.

Chapter 6

Ecological Economics



Three circles enclosed within one another showing how both economy and society are subsets of our planetary ecological system. This view is useful for correcting the misconception, sometimes drawn from the previous "three pillars" diagram that portions of social and economic systems can exist independently from the environment.

Ecological economics is a transdisciplinary field of academic research that aims to address the interdependence and coevolution of human economies and natural ecosystems over time and space. It is distinguished from environmental economics, which is the mainstream economic analysis of the environment, by its treatment of the economy as a subsystem of the ecosystem and its emphasis upon preserving natural capital. One survey of German economists found that ecological and environmental economics are different schools of economic thought, with ecological economists emphasizing "strong" sustainability and rejecting the proposition that natural capital can be substituted by human-made capital.

Ecological economics was founded in the works of Kenneth E. Boulding, Nicholas Georgescu-Roegen, Herman Daly, Robert Costanza, and others. The related field of green economics is, in general, a more politically applied form of the subject.

The identity of ecological economics as a field has been described as fragile, with no generally accepted theoretical framework and a knowledge structure which is not clearly defined. According to ecological economist Malte Faber, ecological economics is defined by its focus on nature, justice, and time. Issues of intergenerational equity, irreversibility of environmental change, uncertainty of long-term outcomes, and sustainable development guide ecological economic analysis and valuation. Ecological economists have questioned fundamental mainstream economic approaches such as cost-benefit analysis, and the separability of economic values from scientific research, contending that economics is unavoidably normative rather than positive (empirical). Positional analysis, which attempts to incorporate time and justice issues, is proposed as an alternative.

Ecological economics includes the study of the metabolism of society, that is, the study of the flows of energy and materials that enter and exit the economic system. This subfield may also be referred to as biophysical economics, bioeconomics, and has links with the applied science of industrial symbiosis. Ecological economics is based on a conceptual model of the economy connected to, and sustained by, a flow of energy, materials, and ecosystem services. Analysts from a variety of disciplines have conducted research on the economy-environment relationship, with concern for energy and material flows and sustainability, environmental quality, and economic development.

Nature and ecology

Environmental Scientist sampling water.

A simple circular flow of income diagram is replaced in ecological economics by a more complex flow diagram reflecting the input of solar energy, which sustains natural inputs and environmental services which are then used as units of production. Once consumed, natural inputs pass out of the economy as pollution and waste. The potential of an environment to provide services and materials is referred to as an "environment's source function", and this function is depleted as resources are consumed or pollution contaminates the resources. The "sink function" describes an environment's ability to absorb and render harmless waste and pollution: when waste output exceeds the limit of the sink function, long-term damage occurs.[:8] Some persistent pollutants, such as some organic pollutants and nuclear waste are absorbed very slowly or not at all; ecological economists emphasize minimizing "cumulative pollutants".[:28] Pollutants affect human health and the health of the climate.

The economic value of natural capital and ecosystem services is accepted by mainstream environmental economics, but is emphasized as especially important in ecological economics. Ecological economists may begin by estimating how to maintain a stable environment before assessing the cost in dollar terms.[:] Ecological economist Robert Costanza led an attempted valuation of the global ecosystem in 1997. Initially published in *Nature*, the article concluded on $33 trillion with a range from $16 trillion to $54 trillion (in 1997, total global GDP was $27 trillion). Half of the value went to nutrient cycling. The open oceans, continental shelves, and estuaries had the highest total value, and the highest per-hectare values went to estuaries, swamps/floodplains, and seagrass/algae beds. The work was criticized by articles in *Ecological Economics* Volume 25, Issue 1, but the critics acknowledged the positive potential for economic valuation of the global ecosystem.:

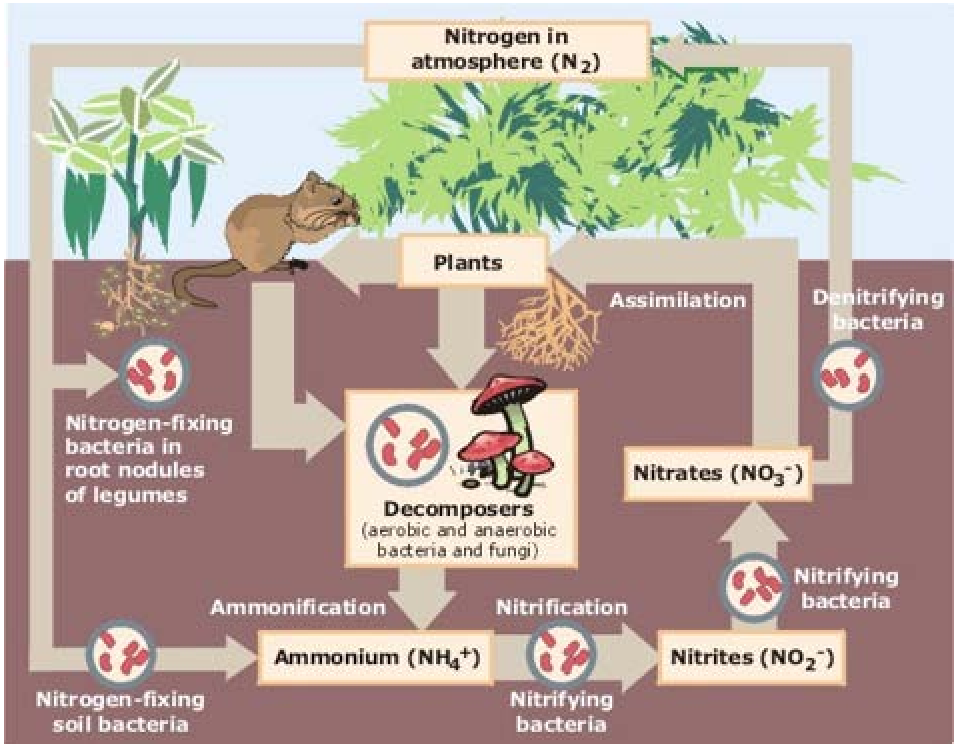
The Earth's carrying capacity is another central question. This was first examined by Thomas Malthus, and more recently in an MIT study entitled *Limits to Growth*. Although the predictions of Malthus have not come to pass, some limit to the Earth's ability to support life are acknowledged. In addition, for real GDP per capita to increase real GDP must increase faster than population growth. Diminishing returns suggest that productivity increases will slow if major technological progress is not made. Food production may become a problem, as erosion, an impending water crisis, and soil salinity (from irrigation) reduce the productivity of agriculture. Ecological economists argue that industrial agriculture, which exacerbates these problems, is not sustainable agriculture, and are generally inclined favorably to organic farming, which also reduces the output of carbon.:

Global wild fisheries are believed to have peaked and begun a decline, with valuable habitat such as estuaries in critical condition.: The aquaculture or farming of piscivorous fish, like salmon, does not help solve the problem because they need to be fed products from other fish. Studies have shown that salmon farming has major negative impacts on wild salmon, as well as the forage fish that need to be caught to feed them.

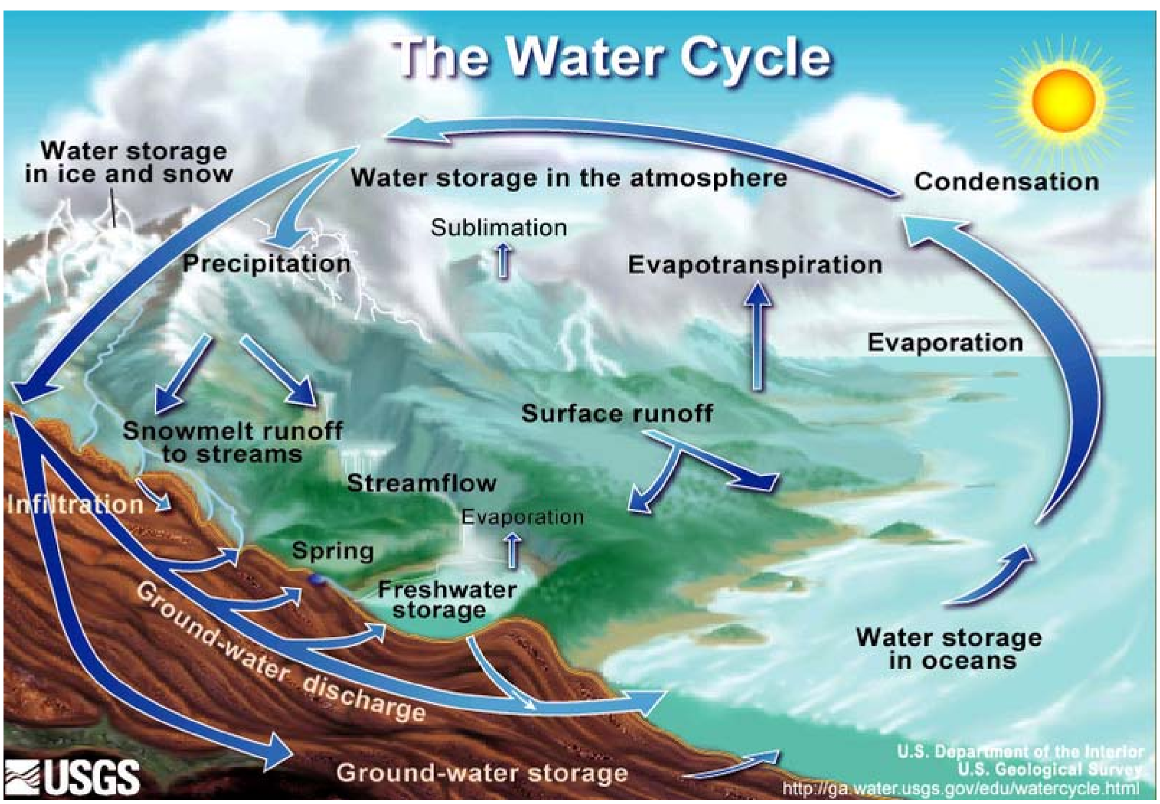
Since animals are higher on the trophic level, they are less efficient sources of food energy. Reduced consumption of meat would reduce the demand for food, but as nations develop, they tend to adopt high-meat diets similar to that of the United States. Genetically modified food (GMF) a conventional solution to the problem, presents numerous problems – Bt corn produces its own Bacillus thuringiensis, but the pest resistance is believed to be only a matter of time.[:31] The overall effect of GMF on yields is contentious, with the USDA and FAO acknowledging that GMFs do not necessarily have higher yields and may even have reduced yields.

Global warming is now widely acknowledged as a major issue, with all national scientific academies expressing agreement on the importance of the issue. As the population growth intensifies and energy demand increases, the world faces an energy crisis. Some economists and scientists forecast a global ecological crisis if energy use is not contained – the Stern report is an example. The disagreement has sparked a vigorous debate on issue of discounting and intergenerational equity.

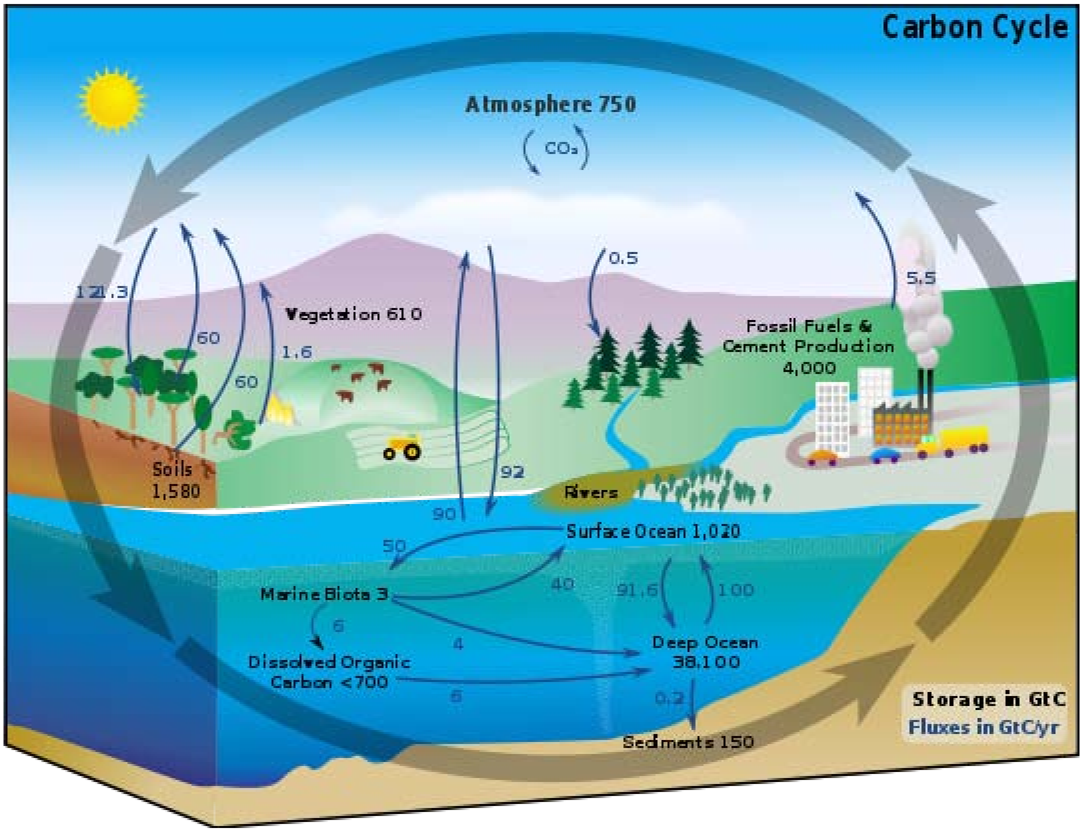
- GLOBAL GEOCHEMICAL CYCLES CRITICAL FOR LIFE



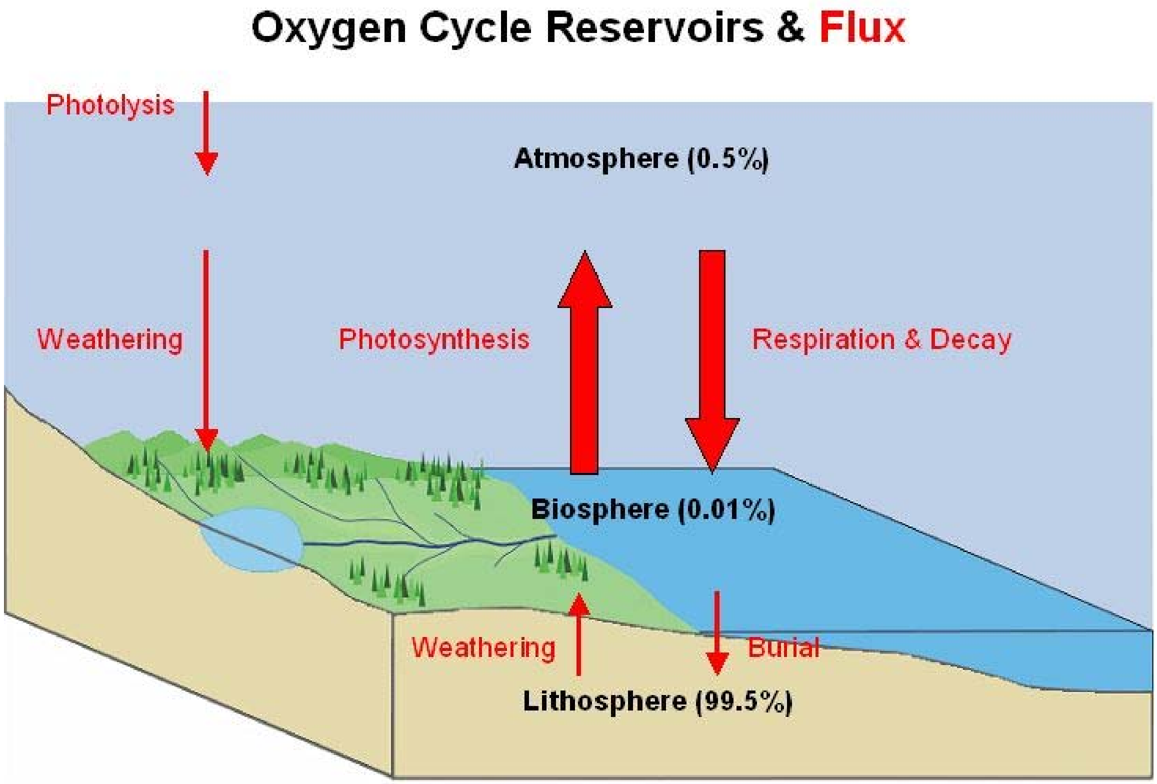
Nitrogen cycle



Water cycle



Carbon cycle



Oxygen cycle

Ethics

Mainstream economics has attempted to become a value-free 'hard science', but ecological economists argue that value-free economics is generally not realistic. Ecological economics is more willing to entertain alternative conceptions of utility, efficiency, and cost-benefits such as positional analysis or multi-criteria analysis. Ecological economics is typically viewed as economics for sustainable development, and may have goals similar to green politics.

Schools of thought

Various competing schools of thought exist in the field. Some are close to resource and environmental economics while others are far more heterodox in outlook. An example of the latter is the *European Society for Ecological Economics*. An example of the former is the Swedish *Beijer International Institute of Ecological Economics.*

Differentiation from mainstream schools

In ecological economics, natural capital is added to the typical capital asset analysis of land, labor, and financial capital. Ecological economics uses tools from mathematical economics, but may apply them more closely to the natural world. Whereas mainstream economists tend to be technological optimists, ecological economists are inclined to be technological pessimists. They reason that the natural world has a limited carrying capacity and that its resources may run out. Since destruction of important environmental resources could be practically irreversible and catastrophic, ecological economists are inclined to justify cautionary measures based on the precautionary principle.

The most cogent example of how the different theories treat similar assets is tropical rainforest ecosystems, most obviously the Yasuni region of Ecuador. While this area has substantial deposits of bitumen it is also one of the most diverse ecosystems on Earth and some estimates establish it has over 200 undiscovered medical substances in its genomes - most of which would be destroyed by logging the forest or mining the bitumen. Effectively, the instructional capital of the genomes is undervalued by both classical and neoclassical means which would view the rainforest primarily as a source of wood, oil/tar and perhaps food. Increasingly the carbon credit for leaving the extremely carbon-intensive ("dirty") bitumen in the ground is also valued - the government of Ecuador set a price of US$350M for an oil lease with the intent of selling it to someone committed to never exercising it at all and instead preserving the rainforest. Bill Clinton, Paul Martin and other former world leaders have become closely involved in this project which includes lobbying for the issue of International Monetary Fund Special Drawing Rights to recognize the rainforest's value directly within the framework of the Bretton Woods institutions. If successful this would be a major victory for advocates of ecological economics as the new mainstream form of economics.

History and development

Early interest in ecology and economics dates back to the 1960s and the work by Kenneth Boulding and Herman Daly, but the first meetings occurred in the 1980s. It began with a 1982 symposium in Sweden which was attended by people who would later be instrumental in the field, including Robert Costanza, Herman Daly, Charles Hall, Ann-Mari Jansson, Bruce Hannon, H.T. Odum, and David Pimentel. Most were ecosystem ecologists or mainstream environmental economists, with the exception of Daly. In 1987, Daly and Costanza edited an issue of *Ecological Modeling* to test the waters. A book titled *Ecological Economics* by Juan Martinez-Alier was published later that year. 1989 saw the foundation of the International Society for Ecological Economics and first publication of its journal *Ecological Economics* by Elsevier. Robert Costanza was the first president of the society and first editor of the journal which is currently edited by Richard Howarth.

European conceptual founders include Nicholas Georgescu-Roegen (1971), William Kapp (1944) and Karl Polanyi (1950). Some key concepts of what is now ecological economics are evident in the writings of E.F. Schumacher, whose book *Small Is Beautiful*

– *A Study of Economics as if People Mattered* (1973) was published just a few years before the first edition of Herman Daly's comprehensive and persuasive *Steady-State Economics* (1977). Other figures include ecologists C.S. Holling, H.T. Odum and Robert Costanza, biologist Gretchen Daily and physicist Robert Ayres. CUNY geography professor David Harvey explicitly added ecological concerns to political economic literature. This parallel development in political economy has been continued by analysts such as sociologist John Bellamy Foster.

The antecedents can be traced back to the Romantics of the 19th century as well as some Enlightenment political economists of that era. Concerns over population were expressed by Thomas Malthus, while John Stuart Mill hypothesized that the "stationary state" of an economy might be something that could be considered desirable, anticipating later insights of modern ecological economists, without having had their experience of the social and ecological costs of the dramatic post-World War II industrial expansion. As Martinez-Alier explores in his book the debate on energy in economic systems can also be traced into the 19th century e.g. Nobel prize-winning chemist, Frederick Soddy (1877–1956). Soddy criticized the prevailing belief of the economy as a perpetual motion machine, capable of generating infinite wealth — a criticism echoed by his intellectual heirs in the now emergent field of ecological economics.

The Romanian economist Nicholas Georgescu-Roegen (1906–1994), who was among Daly's teachers at Vanderbilt University, provided ecological economics with a modern conceptual framework based on the material and energy flows of economic production and consumption. His *magnum opus*, *The Entropy Law and the Economic Process* (1971), has been highly influential.

Articles by Inge Ropke (2004, 2005) and Clive Spash (1999) cover the development and modern history of ecological economics and explain its differentiation from resource and environmental economics, as well as some of the controversy between American and European schools of thought. An article by Robert Costanza, David Stern, Lining He, and Chunbo Ma responded to a call by Mick Common to determine the foundational literature of ecological economics by using citation analysis to examine which books and articles have had the most influence on the development of the field.

Topics

Methodology

The primary objective of ecological economics (EE) is to ground economic thinking and practice in physical reality, especially in the laws of physics (particularly the laws of thermodynamics) and in knowledge of biological systems. It accepts as a goal the improvement of human well-being through development, and seeks to ensure achievement of this through planning for the sustainable development of ecosystems and societies. Of course the terms development and sustainable development are far from lacking controversy. Richard Norgaard argues traditional economics has hi-jacked the development terminology in his book *Development Betrayed*.

Well-being in ecological economics is also differentiated from welfare as found in mainstream economics and the 'new welfare economics' from the 1930s which informs resource and environmental economics. This entails a limited preference utilitarian conception of value i.e., Nature is valuable to our economies, that is because people will pay for its services such as clean air, clean water, encounters with wilderness, etc.

Ecological economics is distinguishable from neoclassical economics primarily by its assertion that the economy is embedded within an environmental system. Ecology deals with the energy and matter transactions of life and the Earth, and the human economy is by definition contained within this system. Ecological economists argue that neoclassical economics has ignored the environment, at best considering it to be a subset of the human economy.

The neoclassical view ignores much of what the natural sciences have taught us about the contributions of nature to the creation of wealth e.g., the planetary endowment of scarce matter and energy, along with the complex and biologically diverse ecosystems that provide goods and ecosystem services directly to human communities: micro- and macro-climate regulation, water recycling, water purification, storm water regulation, waste absorption, food and medicine production, pollination, protection from solar and cosmic radiation, the view of a starry night sky, etc.

There has then been a move to regard such things as natural capital and ecosystems functions as goods and services. However, this is far from uncontroversial within ecology or ecological economics due to the potential for narrowing down values to those found in mainstream economics and the danger of merely regarding Nature as a commodity. This has been referred to as ecologists 'selling out on Nature'. There is then a concern that ecological economics has failed to learn from the extensive literature in environmental ethics about how to structure a plural value system.

Allocation of resources

Resource and neoclassical economics focus primarily on the efficient allocation of resources, and less on two other fundamental economic problems which are central to ecological economics: distribution (equity) and the scale of the economy relative to the ecosystems upon which it is reliant. Ecological Economics also makes a clear distinction between growth (quantitative increase in economic output) and development (qualitative improvement of the quality of life) while arguing that neoclassical economics confuses the two. Ecological economists point out that, beyond modest levels, increased per-capita consumption (the typical economic measure of "standard of living") does not necessarily lead to improvement in human well-being, while this same consumption can have harmful effects on the environment and broader societal well-being.

Strong versus weak sustainability

Ecological economics challenges the conventional approach towards natural resources, claiming that it undervalues natural capital by considering it as interchangeable with human-made capital—labor and technology.

The potential for the substitution of man-made capital for natural capital is an important debate in ecological economics and the economics of sustainability. There is a continuum of views among economists between the strongly neoclassical positions of Robert Solow and Martin Weitzman, at one extreme and the 'entropy pessimists', notably Nicholas Georgescu-Roegen and Herman Daly, at the other.

Neoclassical economists tend to maintain that man-made capital can, in principle, replace all types of natural capital. This is known as the *weak sustainability* view, essentially that every technology can be improved upon or replaced by innovation, and that there is a substitute for any and all scarce materials.

At the other extreme, the *strong sustainability* view argues that the stock of natural resources and ecological functions are irreplaceable. From the premises of strong sustainability, it follows that economic policy has a fiduciary responsibility to the greater ecological world, and that sustainable development must therefore take a different approach to valuing natural resources and ecological functions.

Energy economics

A key concept of energy economics is net energy gain, which recognizes that all energy requires energy to produce. To be useful the energy return on energy invested (*EROEI*) has to be greater than one. The net energy gain from production coal, oil and gas has declined over time as the easiest to produce sources have been most heavily depleted.

Ecological economics generally rejects the view of energy economics that growth in the energy supply is related directly to well being, focusing instead on biodiversity and creativity - or natural capital and individual capital, in the terminology sometimes adopted to describe these economically. In practice, ecological economics focuses primarily on the key issues of uneconomic growth and quality of life. Ecological economists are inclined to acknowledge that much of what is important in human well-being is not analyzable from a strictly economic standpoint and suggests an interdisciplinary approach combining social and natural sciences as a means to address this.

Thermoeconomics is based on the proposition that the role of energy in biological evolution should be defined and understood through the second law of thermodynamics, but also in terms of such economic criteria as productivity, efficiency, and especially the costs and benefits (or profitability) of the various mechanisms for capturing and utilizing available energy to build biomass and do work. As a result, thermoeconomics are often discussed in the field of ecological economics, which itself is related to the fields of sustainability and sustainable development.

Exergy analysis is performed in the field of industrial ecology to use energy more efficiently. The term *exergy*, was coined by Zoran Rant in 1956, but the concept was developed by J. Willard Gibbs. In recent decades, utilization of exergy has spread outside of physics and engineering to the fields of industrial ecology, ecological economics, systems ecology, and energetics.

Energy accounting and balance

An energy balance can be used to track energy through a system, and is a very useful tool for determining resource use and environmental impacts, using the First and Second laws of thermodynamics, to determine how much energy is needed at each point in a system, and in what form that energy is a cost in various environmental issues. The energy accounting system keeps track of energy in, energy out, and non-useful energy versus work done, and transformations within the system.

Scientists have written and speculated on different aspects of energy accounting.

Environmental services

A study was carried out by Costanza and colleagues to determine the 'price' of the services provided by the environment. This was determined by averaging values obtained from a range of studies conducted in very specific context and then transferring these without regard to that context. Dollar figures were averaged to a per hectare number for different types of ecosystem e.g. wetlands, oceans. A total was then produced which came out at 33 trillion US dollars (1997 values), more than twice the total GDP of the world at the time of the study. This study was criticized by pre-ecological and even some environmental economists - for being inconsistent with assumptions of financial capital valuation - and ecological economists - for being inconsistent with an ecological economics focus on biological and physical indicators.

The whole idea of treating ecosystems as goods and services to be valued in monetary terms remains controversial to some. A common objection is that life is precious or priceless, but this demonstrably degrades to it being worthless under the assumptions of any branch of economics. Reducing human bodies to financial values is a necessary part of every branch of economics and not always in the direct terms of insurance or wages. Economics, in principle, assumes that conflict is reduced by agreeing on voluntary contractual relations and prices instead of simply fighting or coercing or tricking others into providing goods or services. In doing so, a provider agrees to surrender time and take bodily risks and other (reputation, financial) risks. Ecosystems are no different than other bodies economically except insofar as they are far less replaceable than typical labour or commodities.

Despite these issues, many ecologists and conservation biologists are pursuing ecosystem valuation. Biodiversity measures in particular appear to be the most promising way to reconcile financial and ecological values, and there are many active efforts in this regard. The growing field of biodiversity finance began to emerge in 2008 in response to many specific proposals such as the Ecuadoran Yasuni proposal or similar ones in the Congo. US news outlets treated the stories as a "threat" to "drill a park" reflecting a previously dominant view that NGOs and governments had the primary responsibility to protect ecosystems. However Peter Barnes and other commentators have recently argued that a guardianship/trustee/commons model is far more effective and takes the decisions out of the political realm.

Commodification of other ecological relations as in carbon credit and direct payments to farmers to preserve ecosystem services are likewise examples that permit private parties to play more direct roles protecting biodiversity. The United Nations Food and Agriculture Organization achieved near-universal agreement in 2008 that such payments directly valuing ecosystem preservation and encouraging permaculture were the only practical way out of a food crisis. The holdouts were all English-speaking countries that export GMOs and promote "free trade" agreements that facilitate their own control of the world transport network: The US, UK, Canada and Australia.

Externalities

Ecological economics is founded upon the view that the neoclassical economics (NCE) assumption that environmental and community costs and benefits are mutually canceling *"externalities"* is not warranted. Juan Martinez Alier, for instance shows that the bulk of consumers are automatically excluded from having an impact upon the prices of commodities, as these consumers are future generations who have not been born yet. The assumptions behind future discounting, which assume that future goods will be cheaper than present goods, has been criticized by Fred Pearce and by the recent Stern Report (although the Stern report itself does employ discounting and has been criticized by ecological economists).

Concerning these externalities, Paul Hawken argues that the only reason why goods produced unsustainably are usually cheaper than goods produced sustainably is due to a hidden subsidy, paid by the non-monetized human environment, community or future generations. These arguments are developed further by Hawken, Amory and Hunter Lovins in "Natural Capitalism: Creating the Next Industrial Revolution".

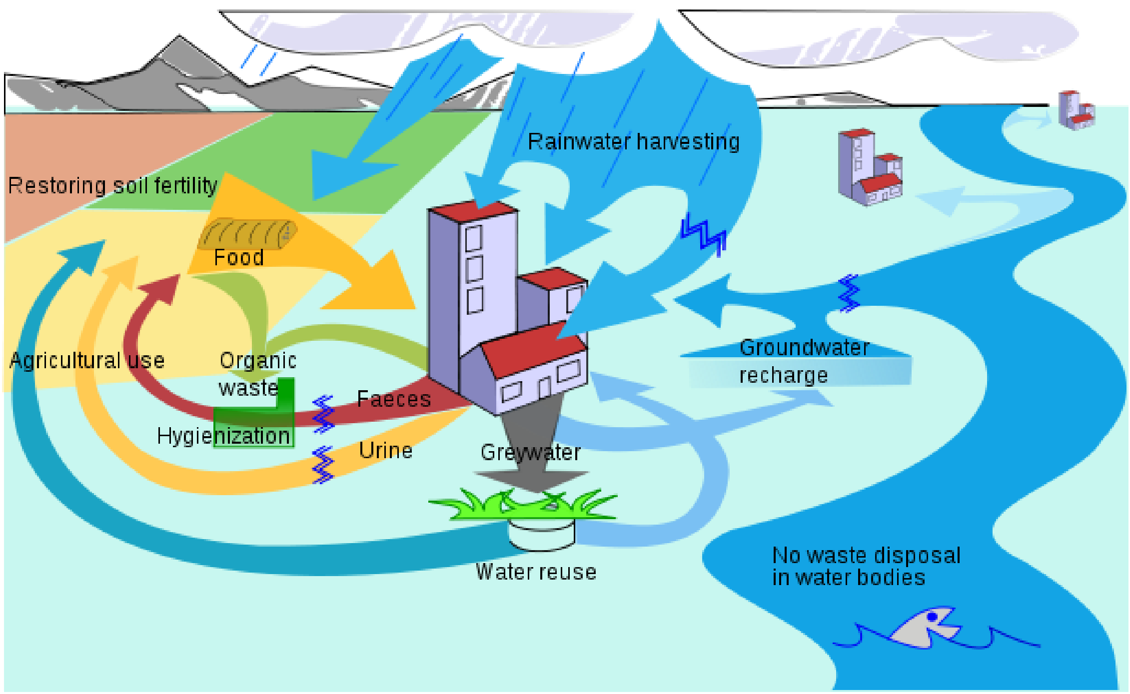
Ecological-Economic Modeling

Mathematical modeling is a powerful tool that is used in ecological economic analysis. Various approaches and techniques include : evolutionary, input-output, neo-Austrian modeling, entropy and thermodynamic models, multi-criteria, and agent-based modeling, the environmental Kuznets curve. Systems Dynamics and GIS are tools used in spatial dynamic landscape simulation modeling.

Chapter 7

Ecological Sanitation

Ecological sanitation, also known as **ecosan** or **eco-san**, is a sanitation process that uses human blackwater and sometimes immediately eliminates fecal pathogens from any still present wastewater (urine) at the source. The objectives are to offer economically and ecologically sustainable and culturally acceptable systems that aim to close the natural nutrient and water cycle.



Introduction to ecological sanitation

Ecological sanitation (ecosan) offers a new philosophy of dealing with what is presently regarded as waste and wastewater. Ecosan is based on the systematic implementation of reuse and recycling of nutrients and water as a hygienically safe, closed-loop and holistic alternative to conventional sanitation solutions. Ecosan systems enable the recovery of nutrients from human faeces and urine for the benefit of agriculture, thus helping to preserve soil fertility, assure food security for future generations, minimize water pollution and recover bioenergy. They ensure that water is used economically and is recycled in a safe way to the greatest possible extent for purposes such as irrigation or groundwater recharge.

The main objectives of ecological sanitation are:

- To reduce the health risks related to sanitation, contaminated water and waste
- To prevent the pollution of surface and ground water
- To prevent the degradation of soil fertility
- To optimise the management of nutrients and water resources.

History of reuse-oriented sanitation approaches

In a very broad sense the recovery and use of urine and feces has been practiced over millennia by almost all cultures. The uses were not limited to agricultural production (although for modern application this may be of most relevance), like the Romans who were well aware of the disinfecting attributes of urine and also used it for washing clothing.

The most widely known example of the diligent collection and use of human excreta in agriculture is China. Reportedly, the Chinese were aware of the benefits of using excreta in crop production before 500 B.C., enabling them to sustain more people at a higher density than any other system of agriculture. The value of "night soil" as a fertilizer was clearly recognized with well developed systems in place to enable the collection of excreta from cities and its transportation to fields.

Elaborate systems were developed in urban centers of Yemen enabling the separation of urine and excreta even in multi-story buildings. Feces were collected from toilets via vertical drop shafts, while urine did not enter the shaft but passed instead along a channel leading through the wall to the outside where it evaporated. Here, feces were not used in agriculture but were dried and burnt as fuel.

In Mexico and Peru, both the Aztec and Inca cultures collected human excreta for agricultural use. In Peru, the Incas had a high regard for excreta as a fertilizer, which was stored, dried and pulverized to be utilized when planting maize.

In the Middle Ages, the use of excreta and greywater was the norm. European cities were rapidly urbanizing and sanitation was becoming an increasingly serious problem, whilst at the same time the cities themselves were becoming an increasingly important source of agricultural nutrients. The practice of using the nutrients in excreta and wastewater for agriculture therefore continued in Europe into the middle of the 19th Century. Farmers, recognizing the value of excreta, were eager to get these fertilizers to increase production and urban sanitation benefited.

The increasing number of research and demonstration projects for excreta reuse carried out in Sweden from the 1980s to the early 21st century aimed at developing hygienically safe closed loop sanitation systems. Similar lines of research began elsewhere, for example in Zimbabwe, in the Netherlands, Norway and Germany. These closed-loop sanitation systems became popular under the name "ecosan", "dewats", "desar", and other abbreviations. They placed their emphasis on the hygenisation of the contaminated flow streams, and shifted the concept from waste disposal to resource conservation and safe reuse.

Concepts of ecological sanitation

Ecological sanitation (Ecosan) is a new holistic paradigm in sanitation, which is based on an overall view of material flows as part of an ecologically and economically sustainable wastewater management system tailored to the needs of the users and to the respective local conditions. It does not favour a specific sanitation technology, but is rather a new philosophy in handling substances that have so far been seen simply as wastewater and water-carried waste for disposal.

According to Esrey et al. (2003) ecological sanitation can be defined as a system that:

- Prevents disease and promotes health
- Protects the environment and conserves water
- Recovers and recycles nutrients and organic matter

Ecosan offers a flexible framework, where centralised elements can be combined with decentralised ones, waterborne with dry sanitation, high-tech with low-tech, etc. By considering a much larger range of options, optimal and economic solutions can be developed for each particular situation.

Thus, the most important advantages of ecological sanitation systems are:

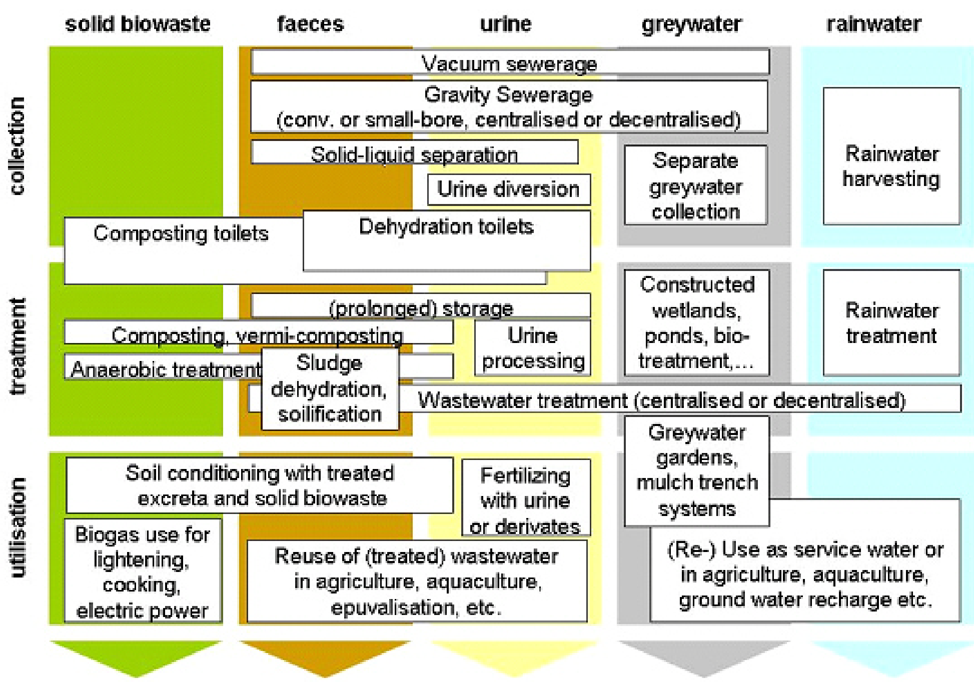
- Improvement of health by minimising the introduction of pathogens from human excreta into the water cycle
- Promotion of safe, hygienic recovery and use of nutrients, organics, trace elements, water and energy
- Preservation of soil fertility
- Contribution to the conservation of resources through lower water consumption, substitution of mineral fertiliser and minimisation of water pollution

- Improvement of agricultural productivity and food security
- Preference for modular, decentralised partial-flow systems for more appropriate cost-efficient solutions adapted to the local situation
- Promotion of a holistic, interdisciplinary approach
- Material flow cycle instead of disposal of valuable resources

Technologies of ecosan systems

Determining ecosan systems as ecological sanitation is not easy, for it is not just one specific technology, but a new approach based on an ecosystem-oriented view of material flows.

The following diagram gives an overview of the different collection, treatment and reuse possibilities of the five flow streams considered in ecological sanitation systems:



Project examples

Examples of ecosan projects can be found among others in the collection of project data sheets of gtz ecosan or on the Enhanced Global Map of ecosan activities by EcoSanRes . In the following some examples are given that underline the diversity of ecosan projects:

Guangxi province, China - large-scale project of urine diverting dehydration toilets
The dissemination programme of ecological dry toilets for Hsinchu County, Guangxi province, one of the poorest provinces in China, started in 1997 with support of UNICEF, SIDA and the Red Cross and has been expanded to 17 provinces until the year 2003. By

this year, the scale of the project had increased to approximately 685,000 toilet units – today more than one million double vault urine diversion dehydration toilets (UDDTs) are installed in rural areas of China.

In UDDTs, urine and faeces are collected separately: The urine is collected in the front and led by a plastic pipe to a storage canister from where it can be used as a fertilizer in agriculture, the faeces fall at the back in one of two ventilated storage chambers and are covered with ash for better dehydration. After about one year of storage the dried material can be removed and used as a soil conditioner in agriculture.

KfW, Frankfurt, Germany - vacuum toilets + greywater treatment The sanitation concept of the modern office building "Ostarkarde" of the KfW Bankengruppe in Frankfurt is based on a separate excreta and greywater collection. While urine and faeces are collected via vacuum toilets and a vacuum sewerage using much less water for flushing, the greywater from hand washing and kitchen is collected and treated separately in a compact activated sludge reactor combined with membrane filtration. The treated greywater is then reused for toilet flushing and cleaning water. The amount of greywater can be reduced by 76% by this cost-efficient system which could be one of the prior choices for sanitation systems of newly constructed office buildings.

Tanum Municipality in Sweden has introduced urine separation toilets to recover phosphorus.

Arguments for the use of ecological sanitation

Often, water used in flush toilets is of drinking quality. Only 1% of global water is drinkable, therefore, it is a precious resource. Water fit to be drunk is being used for other purposes that can use lesser quality water, such as toilets.

Mixing feces and urine makes treatment difficult. All waste water treatment plants use some natural/biological processes, but nature does not normally have this waste water, so there are no microbes that can deal with this mix. In order to treat waste, treatment plants have to do this in stages. Each stage treats a different component of the mix by creating the right environment for microbes to do their work (aerobic, anaerobic, anoxic and the right pH). This is costly and requires energy.

A mix of domestic and industrial effluent in water cannot be treated properly, for heavy metals and other pollutants make this water unsuitable for reuse. This is normally discharged into the ground or water bodies.

Because of the complexity of the treatment process, treatment plants tend to be large. This requires costly infrastructure to build and maintain it, often out of the reach of poorer communities.

John Jeavons argues that "Each person's urine and manure contain approximately enough nutrients to produce enough food to feed that person." Urea is the major component of urine, yet we produce vast quantities of urea by using fossil fuels. By properly managing urine, treatment costs as well as fertilizer costs can be reduced. Feces also contains recognized nutrients, and could be used for modern agriculture, as micronutrient deficiency is a significant problem.

Chapter 8

Ecological Engineering Methods & Human Ecology

Ecological Engineering Methods

Ecological Engineering Methods (also known as Biological Engineering or ECO-Engineering) is when researchers try to tap biologically-based energy sources. Some projects include engineering new organisms that produce hydrogen from water and sunlight in environmentally friendly ways with no waste products, and transforming the way man interacts with the environment. One of the more familiar techniques of ECO-Engineering is Bioremediation. Using oil-eating bacteria created by Eco-Engineering, Bioremidiation is applied to oil spills and chemical spills worldwide.

Primary and Secondary methods of producing energy

We have to distinguish between Primary and Secondary methods of producing energy. Making hydrogen from water by electrolysis will use more energy than is available in the hydrogen, because processing always has **nonzero wastage**. When the hydrogen is produced there are all the emissions for generating electricity from fossil fuels for electrolysis, but when the hydrogen is used in automobiles as fuel the automobiles will emit harmless water vapour. If power is made from fossil fuels, then the hydrogen automobile fuel, as a whole, causes even more emissions than directly burning fossil fuels in automobiles.

Non-chemical Primary fuel is less polluting

The trick is that if we use non-chemical Primary fuels, like Solar energy or Nuclear energy, then the complete process is less polluting.

Emissions versus hydrogen

As long as fossil fuels are used for producing hydrogen, the only benefit is that, although it produces even more emissions, these emissions are near Power Generating Stations, which can be kept away from urban areas. Earth as a whole suffers more emissions than without use of hydrogen automobile fuel.

Emission control

Emission control implies control on use of fossil fuels. The fossil fuels can produce greenhouse gases, such as carbon dioxide and others. So, we need to control the use of fossil fuels, because they can harm our world. We can use petrol without plumbum (unleaded gasoline) because this petrol does not release the smoke that can pollute our environment.

Greenhouse gas capture

Nuclear or solar energy can be used to actively capture greenhouse gases from the atmosphere and convert them into non-polluting chemical compounds, in other words, to convert atmospheric carbon dioxide into solid carbon and gaseous oxygen. Earth will get more heat (waste heat of the nuclear power station, and energy consumption of the processes, minus the internal energy added to carbon and oxygen when chemically separating them out of the carbon dioxide). Also, the removed carbon dioxide will reduce it in the atmosphere. Instead of direct chemical reactions, the capture could be done by biological means, accelerated with help of nuclear energy. In other words, air separation plants could run on nuclear energy, capturing liquid or solid carbon dioxide. Then, possibly, chlorophyll-containing genetically modified algae could be used to convert it into fixed carbon compounds. We could have an interim technology of spraying microspheres loaded with algae into the open atmosphere from aircraft or even balloons. If the microspheres were small enough, these could remain in the air for long times, and go on converting carbon dioxide with help of direct solar energy.

Theory

The technology of artificially accelerated reduction of already emitted green house gases is as yet unexplored but is theoretically possible.

Traditional versus Ecological Engineering

Traditional engineering use the concrete [overshoes?] to compensate the flaws which have mentioned above, but this method can not really reinforce the natural environment's power—over-using the concrete [overshoes?] can enlarge the destruction for natural environment. Recently, the new method, Ecological Engineering Methods, has been invented, so the nature-working method engineer has attracted people's attention, respect and broad application. Moreover, nature-working method engineer notice the importance of the environment protection, soil and water conservation, and reduction and protection for the natural calamity, thus, people can maintain the sustainable exploitation permanently.

Human Ecology

Human ecology is the interdisciplinary or transdisciplinary study of the relationship between humans and their natural, social, and built environments.

Development of human ecology

Ecology as a discipline was technically born when Ernst Haeckel used the word "oekologie" in 1866 to describe the study of an organism's relationship to its environment. Ecology was revolutionary at this time because it encouraged interdisciplinarity within the sciences—it created a bridge between the physical sciences and the biological sciences in order to study systems of both biotic and abiotic factors.

Human ecology is composed of concepts from ecology like interconnectivity, community behavior, and spatial organization. From the beginning, human ecology was present in geography and sociology, but also in biological ecology and zoology. However, it was the social scientists who applied ecological ideas to humans in a rigorous way. Throughout the 20th century, few biological ecologists really tackled human ecology, but they tended to focus on humans' impact on the biotic world----which is only half of the picture. Paul Sears is the perfect example of this, an ecologist who realized the disastrous effects that humans were having on the environment and called for human ecology to act as a means to solve them. However, some social scientists expanded human ecology to include also the physical environment's impact on people.

It is interesting to note that although social scientist human ecologists got their ideas from biological ecologists, these early biological ecologists had originally adapted social concepts to the natural world. These concepts that transcended disciplines and passed from the social to the biological and back to the social are the basis for human ecology.

The academic foundations of a human ecology can be attributed to the sociology department at the University of Chicago and to the work of Robert E. Park and Ernest W. Burgess' 1921 book Introduction to the Science of Sociology. Park and Burgess used ecological concepts like those from Frederick Clements and Charles Darwin to describe human systems, specifically focusing on cities. Their student, Roderick McKenzie also played an important role in solidifying human ecology as a sub-discipline within the Chicago school. They emphasized that the difference between human ecology and the ecology of other organisms is that human societies are organized on not only the biotic level but the cultural level as well.

Human ecology as human-environment interactions is an ancient idea in geography. In the modern era, the term appears as early as 1908 in the discipline (Titles and Abstracts of Papers Presented to the Association from 1904 to 1910, Inclusive). Harlan Barrows addresses the topic in his presidential speech to the Association of American Geographers in 1923. Barrows' speech is an attempt to redefine geography as the science of human ecology, emphasizing its study of humans' relationships with the land instead of just a regional study of the physical land.

In the early 1950s anthropologists, led by Julian H. Steward, began to further develop this human ecological study of culture, asserting that it is the intermediary between humans and their environments and what makes humans unique. Anthropologists had long been interested in humans' direct relationships with their environments so it was easy for them to incorporate human ecology into their discipline.

Psychological ecology was also developing at the same time—a field that expanded a person's "environment" to include their mental representation of it and focused on studying people's behavior under field conditions instead of in a controlled laboratory setting. Kurt Lewin emphasized that the "ecology" of this mental world was the study of relations within consciousness, dramatically shifting the term but further expanding the realm of human ecology.

Ecological ideas also showed up in economics, with Kenneth E. Boulding being the strongest proponent for integrating the two disciplines that share semantic origins ("eco" meaning house). Boulding drew parallels between ecology and economics, most generally in that they are both studies of individuals as members of a system, and indicated that the "household of man" and the "household of nature" could somehow be integrated to create a perspective of greater value.

In the late 1960s, ecological concepts started to become integrated into the applied fields, namely architecture, landscape architecture, and planning. Ian McHarg called for a future when all planning would be "human ecological planning" by default, always bound up in humans' relationships with their environments. He emphasized local, place-based planning that takes into consideration all the "layers" of information from geology to botany to zoology to cultural history.

In these early years, human ecology was still deeply enmeshed in its respective disciplines: geography, sociology, anthropology, psychology, and economics. Through the 1970s and 80s scholars like Gerald L. Young and Britta Jungen began to call for a greater integration between all of the scattered disciplines that had each established some kind of ecological thinking. It was clear that throughout the 20th century human ecology was solidly multidisciplinary, in that it included people from a vast variety of disciplines, but it had not yet become interdisciplinary. During the 1970s and 80s this slowly began to change as more interdisciplinary programs, institutions, and organizations became founded focusing on human ecology.

Pioneers and proponents

Many people have contributed to the study of human ecology. The following are some of the most influential scholars:

- Harlan H. Barrows was a geographer who considered human ecology to be the unique field of geography. Barrows regarded human ecology as the relation between geography and the environment and divides it into three areas: economic geography (what people need and want), political geography (relating to organizations), and social geography (connections between people).

- Robert Ezra Park was an urban sociologist who considered human ecology as the study of the relationship between biotic balance and social equilibrium. He emphasized the cultural structure of human society which he separated into groups: ecological, economic, political, and moral.

- Kurt Lewin, a psychologist, worked for the US government during World War II to change people's attitudes toward rationing. In his study, he used "the environment" to describe the mental environment, expanding human ecology into the world of the mind.

- Kenneth E. Boulding, an economist, saw a strong correlation between economics and ecology based around five basic similarities between the two: 1) Both study individuals as members of a species (for ecology, populations of individuals, and for economics, populations of commodities). 2) Both have a concept of equilibrium (for ecology, an equilibrium of populations, and for economics, an equilibrium of price systems). 3) Both involve a system exchange among their various individuals and species that is important in determining equilibrium. 4) Both imply some concept of development. 5) Both are subject to their equilibriums distorted by policy (for ecology, agriculture, and for economics, government).

- As an anthropologist, Julian Steward emphasized the role that culture has in explaining the nature of human societies. He considered human society to be dictated by much more than the immediate physical environment and biotic assemblage. The nature of local group is determined by both local adaptations and larger institutions.

- Roderick D. McKenzie was a sociologist associated with the University of Chicago. McKenzie believed human ecology to be concerned with the process of spatial grouping of interacting human beings or of interrelated human institutions.

- Gerald L. Young was an influential player in the development of Human Ecology. He was the fourth president of Society for Human Ecology (SHE) and is considered one of SHE’s founders. Young is a recognized leader in pulling together the field of human ecology for his scholarly publications in human ecology, including “Origins of Human Ecology” and “The Shadows of Consumption: Consequences for the Global Environment."

- Ian McHarg was a landscape architect and writer on regional planning using natural systems. He was the founder of the department of landscape architecture at the University of Pennsylvania in the United States. His 1969 book Design with Nature pioneered the concept of ecological planning.

- Rusong Wang, an urban systems ecologist at the Chinese Academy of Sciences, defines human ecology, in Chinese terms as the science of the living state or dynamics of the human being, driven by objective and subjective factors. It involves understanding, planning, and management. According to Wang, Chinese human ecologists are searching for a feasible future for their nation that includes high efficiency, sustainable development, and harmonious relationships between social, economic, and natural systems.

- Dieter Steiner, at the Swiss Federal Institute of Technology, had a vision of how to combat the global environmental crises by integrating the sciences with outside disciplines, understanding our evolutionary past, and developing personal integration and relatedness to the world outside the self. He developed many conceptual frameworks to better visualize how to go about these processes. Along with Markus Nauser, he edited the "Human Ecology: fragments of anti-fragmentary views of the world."

- Gregory Bateson, generally known as a British anthropologist, contributed to human ecology in the realm of the ecology of mind. He was opposed to the way scientists try to reduce everything to matter; his goal was to re-introduce the mind into the equation. He emphasized the importance of looking at the world not just though reductionist logic, but to understand the connections in the "pattern which connects" all of our minds through stories.

- Stephen Vickers Boyden contributed to human ecology while at the Australia National University working on a comprehensive study of Hong Kong's unique human ecological situation. This study was the basis for UNESCO's Man in the Biosphere Program. Biohistory: The Interplay Between Human Society and the Biosphere generated the Hong Kong Human Ecology Programme.

- Bonnie McKay is a professor and chair of the department of human ecology at Rutgers University.

- Gary Haq is a Human Ecologist and Senior Research Associate at the Stockholm Environment Institute at the University of York and often writes for the Yorkshire Post.

Concepts

Many human ecological concepts come from ecology.

- Perhaps the most fundamental concept of human ecology is interaction, as an assumption that everything interacts with other things and a basis for all further analysis. Interaction is a function of scale, but should be extended to be a function of diversity and complexity.

- Levels of integration is the concept that entities are organized on levels of different scale for better analysis, for example from the level of the molecule, the individual, the family, the community, the population, the biosphere, or the universe.

- Human ecology expands functionalism from ecology to the human mind. People's perception of a complex world is a function of their ability to be able to comprehend beyond the immediate, both in time and in space. This concept manifested in the popular slogan promoting sustainability: "think global, act local." Moreover, people's conception of community stems from not only their physical location but their mental and emotional connections and varies from "community as place, community as way of life, or community of collective action."

- Diversity and stability are contentious topics in ecology; current research shows that ecosystems are less stable than originally thought and high diversity does not immediately translate into high stability. These have not often been applied to human ecology.

- Systems analysis is one way to understand human ecology, however many topics are more complex and it is important to realize that systems analysis is only one way to understand them and fairly simplified. Most systems are not closed and therefore require simplification in order to study them.

- Spatial analysis is essential to human ecology because many of the problems of relations between humans and their environments are physical.

- A gestalt perspective or holistic viewpoint is important to human ecology because it recognizes that we can gain understanding of a system by looking at it as a whole.

- Monodisciplinary: Studies focusing on one specific area. Most institutions of higher learning award degrees based on monodisciplinary majors intended to prepare students for work in a specific discipline.

- Multidisciplinary: A variety of subjects studied concurrently. A liberal arts degree requires students to study a variety of subjects in order to prepare them to be effective citizens in a complex society.

- Interdisciplinary: Integration between disciplines. A human ecological education integrates ideas from different disciplines in order to better addressing complex problems dealing with human/environment (whether social, physical, or mental) interactions.

- Transdisciplinary: A perspective that transcends disciplines. A human ecological education goes beyond integrating different disciplines, creating a worldview that assumes an inherent connectivity when better addressing problems relating to human/environment interactions, but still relying on solid disciplinary foundation.

Educational Programs

Colleges and universities around the world offer classes, programs and degrees in human ecology. Listed below are a sample of these institutions and the programs they offer.

- ASHE- Australian School of Human Ecology.

Human Ecology is intended as a Unifying Science of the Future, a Science of Relatedness and Inter-connectedness.Rich content, free to access.

- The Australian National University's Fenner School of Environment and Society takes an interdisciplinary perspective in their education and research—integrating skills and expertise from different disciplines to address issues of sustainability and the environment. The ANU offers a major in Human Ecology.

- A Masters of Human Ecology degree is awarded at Vrije Universiteit Brussel in Brussels Belgium. Here students learn about different interdisciplinary research approaches and gain skills in conducting their own interdisciplinary research. Emphasis is also placed on the scientific methods of studying human /environments interactions.

- College of the Atlantic in Bar Harbor, Maine USA, was founded in 1969 by academics who recognized that a new way of thinking was needed in order to solve world problems, a way of thinking that is beyond disciplines. All students at College of the Atlantic receive a degree in Human Ecology – tying their varied interests into their self-designed field of study. The school is not organized by departments and instead sees the study of human ecology as a way to connect disciplines and engage all kinds of knowledge in order to inform action.

- Cornell University in Ithaca, New York USA, has a College of Human Ecology where students focus their study around social topics or themes such as Design and Technology, Development and the Life Course, and Economic and Social Well-Being. The College creates interdisciplinary fields of study by incorporating the social and natural sciences into these topics. Through the integration of these fields, the College hopes to "advance and improve the human condition."

- Lund University in Sweden offers a Masters Program in Human Ecology in which students focus on the issues of sustainability while exploring the different cultural, economic, environmental, and social perceptions and dimensions involved.

- Rutgers School of Environmental and Biological Sciences in New Brunswick New Jersey USA, has a Department of Human Ecology, where professors from diverse disciplines in both the natural and social sciences study the relationship of humans to environmental problems and work to address them.

- Ambedkar University, Delhi's School of Human Ecology offers a Masters Program in Environment and Development to equip students to address the challenges related to the environment as it centrally impacts approach towards development.

- Stanford University offers a Ph.D. in Anthropology with an "Ecology and Environment" focus. Particular strengths include human behavioral ecology, demography and health, and the interdisciplinary study of human subsistence and livelihood. Stanford also offers a Ph.D. through the Emmett Interdisciplinary Program in Environment and Resources, through which students can pursue interdisciplinary research programs in human ecology, broadly construed.

- The University of California at Davis in the United States, has a graduate group in Ecology which offers a "program of emphasis" in Environmental Policy and Human Ecology. In this program students explore the interactions between humans and their environment, what the present conflicts are, and how to address them. They also look at human populations and behavior through a research lens—applying ecology principles to their study.

- University College London's Human Ecology Research Group uses research in history, anthropology, GIS, and the environmental sciences while taking a multidisciplinary approach in their research on the social impacts of environmental degradation.

- The University of Geneva Human Ecology Group brings economics and social sciences into their environmental science studies.

- University of Gothenburg in Sweden has one of the first interdisciplinary PhD human ecology programs in the world.

- The University of South Africa (UNISA) possess a department of human ecology focused on community agriculture.

- University of Tokyo's Department of Human Ecology studies the environment's effect on human health and populations and in turn human's effect on the environment.

- The Wild Rockies Field Institute fosters students' understanding of the complex relationships between ecological processes and human behavior through multidisciplinary, experiential field courses.

Human Ecology Organizations

- The Society for Human Ecology (SHE) is an international society focused on applying and promoting ecological perspectives to research and education. Members come from all over the world and from varied interdisciplinary professions. In their biannual journal, Human Ecology Review, SHE publishes research, commentary, and reviews relevant to Human Ecology. SHE holds regular conferences, workshops, and symposia and they work with other organizations to sponsor related activities that seek to "integrate work among professionals in fields pertaining to human ecology."

- The Centre for Human Ecology in Scotland offers challenging, interdisciplinary courses in social justice and environmental action. As an institute, it works as a network to address global issues and help organizations become more sustainable. By exploring social and environmental issues through a more holistic perspective, CHE hopes to bring about a better world.

- The Commonwealth Human Ecology Council (CHEC) is a humanitarian organization that encourages local, national, and international application of human and social ecological principles. As an international organization it works with governments, the private sector, and the public and it is an "operational force in the Commonwealth and United Nation's spheres of influence."

- The German Society of Human Ecology (Deutsche Gesellschaft für Humanökologie) was founded in 1975 in Reisensburg near Günzburg, Germany. In its early years, DGH was influenced primarily by social medicine. Later the society expanded to include other sciences and policy related. Today it is a forum which brings together experts from all fields of environmental sciences, teachers, doctors, engineers, and administrators to discuss ideas and learn from each. Since 1989 the DGH has held its annual scientific meetings on interdisciplinary themes.

Journals

- Advances in Human Ecology

- Human Ecology

- Human Ecology Review

- Journal of Human Ecology

Recent Trends

While theoretical discussions continue, research published in [Human Ecology Review] suggests that recent discourse has shifted toward applying principles of human ecology. Some of these applications focus instead on addressing problems that cross disciplinary boundaries or transcend those boundaries altogether. Scholarship has increasingly tended away from Young's idea of a "unified theory" of human ecological knowledge—that human ecology may emerge as its own discipline—and more toward the pluralism best espoused by Paul Shepard: that human ecology is healthiest when "running out in all directions.". But human ecology is neither anti-discipline nor anti-theory, rather it is the ongoing attempt to formulate, synthesize, and apply theory to bridge the widening schism between man and nature. This new human ecology emphasizes complexity over reductionism, focuses on changes over stable states, and expands ecological concepts beyond plants and animals to include people.

There is wide agreement that human ecology seeks to integrate diverse perspectives. The growing popularity of liberal arts colleges have increased understanding and recognition of an interdisciplinary college education in the United States and thus human ecology—but mostly in academic circles. Paul Sears was an early proponent of applying human ecology. He saw the vast “explosion” of problems humans were creating for the environment and reminded us that “what is important is the work to be done rather than the label."

In applied fields

In the applied fields of engineering, environmental planning, architecture, and landscape architecture, human ecology has continued to gain more currency.

Proponents of the new urbanism movement, like James Howard Kunstler and Andres Duany, have embraced the term human ecology as way to describe the problem of—and prescribe the solutions for—the landscapes and lifestyles of an automobile oriented society. Duany has called the human ecology movement to be "the agenda for the years ahead."

While McHargian planning is still widely respected, the landscape urbanism movement seeks a new understanding between human and environment relations. Among these theorists is Frederich Steiner, who published Human Ecology: Following Nature's Lead in 2002 which focuses on the relationships among landscape, culture, and planning. The work highlights the beauty of scientific inquiry by revealing those purely human dimensions which underlie our concepts of ecology. While Steiner discusses specific ecological settings, such as cityscapes and waterscapes, and the relationships between socio-cultural and environmental regions, he also takes a diverse approach to ecology----considering even the unique synthesis between ecology and political geography.

Deiter Steiner's 2003 Human Ecology: Fragments of Anti-fragmentary view of the world is an important expose of recent trends in human ecology. Part literature review, the book is divided into four sections: "human ecology", "the implicit and the explicit", "structuration", and "the regional dimension". Much of the work stresses the need for transciplinarity, antidualism, and wholeness of perspective.

In art

While some of the early writers considered how art fit into a human ecology, it was Sears who posed the idea that in the long run human ecology will in fact look more like art. Bill Carpenter (1986) calls human ecology the "possibility of an aesthetic science," renewing dialogue about how art fits into a human ecological perspective. According to Carpenter, human ecology as an aesthetic science counters the disciplinary fragmentation of knowledge by examining human consciousness.

In education

While the reputation of human ecology in institutions of higher learning is growing, there is no evidence of human ecology at the primary and secondary education levels. Educational theorist Sir Ken Robinson has called for the need to diversify education so as to promote creativity in academic and non-academic (i.e.- educate their "whole being") activities to constitute a "new conception of human ecology."