Ecology

Ecology

- **Ecology** (from Greek: οἶκος, "house" and -λογία, "study of") is the study of the relationships between living organisms, including humans, and their physical environment. Ecology considers organisms at the individual, population, community, ecosystems, and biosphere level. Ecology overlaps with the closely related sciences of biogeography, evolutionary biology, genetics, ethology and natural history. Ecology is a branch of biology, and it is not synonymous with environmentalism.
- Among other things, ecology is the study of:
    - Life processes, antifragility, interactions, and adaptations
    - The movement of materials and energy through living communities
    - The successional development of ecosystems
    - Cooperation, competition and predation within and between species.
    - The abundance, biomass, and distribution of organisms in the context of the environment.
    - Patterns of biodiversity and its effect on ecosystem processes
- Ecology has practical applications in conservation biology, wetland management, natural resource management (agroecology, agriculture, forestry, agroforestry, fisheries), city planning (urban ecology), community health, economics, basic and applied science, and human social interaction (human ecology).
- The word "ecology" ("Ökologie") was coined in 1866 by the German scientist Ernst Haeckel, and it became a rigorous science in the late 19th century. Evolutionary concepts relating to adaptation and natural selection are cornerstones of modern ecological theory.
- Ecosystems are dynamically interacting systems of organisms, the communities they make up, and the non-living components of their environment. Ecosystem processes, such as primary production, nutrient cycling, and niche construction, regulate the flux of energy and matter through an environment.
- Ecosystems have biophysical feedback mechanisms that moderate processes acting on living (biotic) and non-living (abiotic) components of the planet. Ecosystems sustain life-supporting functions and provide ecosystem

services like biomass production (food, fuel, fiber, and medicine), the regulation of climate, global biogeochemical cycles, water filtration, soil formation, erosion control, flood protection, and many other natural features of scientific, historical, economic, or intrinsic value.

Levels, scope, and scale of organization

- The scope of ecology contains a wide array of interacting levels of organization spanning micro-level (e.g., cells) to a planetary scale (e.g., biosphere) phenomena.
- Ecosystems, for example, contain abiotic resources and interacting life forms (i.e., individual organisms that aggregate into populations which aggregate into distinct ecological communities). Ecosystems are dynamic, they do not always follow a linear successional path, but they are always changing, sometimes rapidly and sometimes so slowly that it can take thousands of years for ecological processes to bring about certain successional stages of a forest.
- An ecosystem's area 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 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.
- The nature of connections in ecological communities cannot be explained by knowing the details of each species in isolation, because the emergent pattern is neither revealed nor predicted until the ecosystem is studied as an integrated whole.
- Some ecological principles, however, do exhibit collective properties where the sum of the components explain the properties of the whole, such as birth rates of a population being equal to the sum of individual births over a designated time frame.
- The main subdisciplines of ecology, population (or community) ecology and ecosystem ecology, exhibit a difference not only of scale but also of two contrasting paradigms in the field.
- The former focuses on organisms' distribution and abundance, while the latter focuses on materials and energy fluxes.

Hierarchy

- The scale of ecological dynamics can operate like a closed system, such as aphids migrating on a single tree, while at the same time remain open with regard to broader scale influences, such as atmosphere or climate.
- Hence, ecologists classify ecosystems hierarchically by analyzing data collected from finer scale units, such as vegetation associations, climate, and soil types, and integrate this information to identify emergent patterns of uniform organization and processes that operate on local to regional, landscape, and chronological scales.

- To structure the study of ecology into a conceptually manageable framework, the biological world is organized into a nested hierarchy, ranging in scale from genes, to cells, to tissues, to organs, to organisms, to species, to populations, to communities, to ecosystems, to biomes, and up to the level of the biosphere.
- This framework forms a panarchy[8] and exhibits non-linear behaviors; this means that "effect and cause are disproportionate, so that small changes to critical variables, such as the number of nitrogen fixers, can lead to disproportionate, perhaps irreversible, changes in the system properties."

Biodiversity

- Biodiversity (an abbreviation of "biological diversity") describes the diversity of life from genes to ecosystems and spans every level of biological organization.
- The term has several interpretations, and there are many ways to index, measure, characterize, and represent its complex organization.
- Biodiversity includes species diversity, ecosystem diversity, and genetic diversity and scientists are interested in the way that this diversity affects the complex ecological processes operating at and among these respective levels.
- Biodiversity plays an important role in ecosystem services which by definition maintain and improve human quality of life.
- Conservation priorities and management techniques require different approaches and considerations to address the full ecological scope of biodiversity.
- Natural capital that supports populations is critical for maintaining ecosystem servicesand species migration (e.g., riverine fish runs and avian insect control) has been implicated as one mechanism by which those service losses are experienced.
- An understanding of biodiversity has practical applications for species and ecosystem-level conservation planners as they make management recommendations to consulting firms, governments, and industry.

Habitat

- The habitat of a species 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, a habitat might be an aquatic or terrestrial environment that can be further categorized as a montane or alpine ecosystem.
- Habitat shifts provide important evidence of competition in nature where one population changes relative to the habitats that most other individuals of the species occupy.

- For example, one population of a species of tropical lizard (*Tropidurus hispidus*) has a flattened body relative to the main populations that live in open savanna.
- The population that lives in an isolated rock outcrop hides in crevasses where its flattened body offers a selective advantage.
- Habitat shifts also occur in the developmental life history of amphibians, and in insects that transition from aquatic to terrestrial habitats.
- Biotope and habitat are sometimes used interchangeably, but the former applies to a community's environment, whereas the latter applies to a species' environment.

Niche

- Definitions of the niche date back to 1917, but G. Evelyn Hutchinson made conceptual advances in 1957 by introducing a widely adopted definition: "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 Hutchinsonian niche is defined more technically as a "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*."
- Biogeographical patterns and range distributions are explained or predicted through knowledge 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 may influence its survival. Genes play an important role in the interplay of development and environmental expression of traits.
- Resident species evolve traits that are fitted to the selection pressures of 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 states that two species cannot coexist indefinitely by living off the same limiting resource; one will always out-compete the other.
- When similarly adapted species overlap geographically, closer inspection reveals subtle ecological differences in their habitat or dietary requirements.
- Some models and empirical studies, however, suggest that disturbances can stabilize the co-evolution and shared niche occupancy of similar species inhabiting species-rich communities.

- The habitat plus the niche is called the ecotope, which is defined as the full range of environmental and biological variables affecting an entire species

Niche construction

- Organisms are subject to environmental pressures, but they also modify their habitats.
- The regulatory feedback between organisms and their environment can affect conditions from local (e.g., a beaver pond) to global scales, over time and even after death, such as decaying logs or silica skeleton deposits from marine organisms.
- The process and concept of ecosystem engineering are related to niche construction, but the former relates only to the physical modifications of the habitat whereas the latter also considers the evolutionary implications of physical changes to the environment and the feedback this causes on the process of natural selection.
- 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 influence that organisms have on the ecosystem and evolutionary process.
- The term "niche construction" is more often used in reference to the under-appreciated feedback mechanisms 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 is subject to the forces of natural selection.
- Moreover, a nest can survive over successive generations, so that progeny inherit both genetic material and a legacy niche that was constructed before their time.

Biome

- Biomes are larger units of organization that categorize regions of the Earth's ecosystems, mainly according to the structure and composition of vegetation.
- There are different methods to define the 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.

- Biomes include tropical rainforest, temperate broadleaf and mixed forest, temperate deciduous forest, taiga, tundra, hot desert, and polar desert.
- Other researchers have recently categorized other biomes, such as the human and oceanic microbiomes.
- To a microbe, the human body is a habitat and a landscape.
- Microbiomes were discovered largely through advances in molecular genetics, which 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

- The largest scale of ecological organization is the biosphere: the total sum of ecosystems on the planet.
- Ecological relationships regulate the flux of energy, nutrients, and climate all the way up to the planetary scale.
- For example, the dynamic history of the planetary atmosphere's CO_2 and O_2 composition has been affected by the biogenic flux of gases coming from respiration and photosynthesis, with levels fluctuating over time in relation to the ecology and evolution of plants and animals.
- Ecological theory has also been used to explain self-emergent regulatory phenomena at the planetary scale: for example, the Gaia hypothesis is an example of holism applied in ecological theory.[46]
- The Gaia hypothesis states that there is an emergent feedback loop generated by the metabolism of living organisms that maintains the core temperature of the Earth and atmospheric conditions within a narrow self-regulating range of tolerance.

Population ecology

- Population ecology studies the dynamics of species populations and how these populations interact with the wider environment.
- 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 which states, "a population will grow (or decline) exponentially as long as the environment experienced by all individuals in the population remains constant."
- Simplified population models usually start with four variables: death, birth, immigration, and emigration.
- An example of an introductory population model describes a closed population, such as on an island, where immigration and emigration does not take place.
- Hypotheses are evaluated with reference to a null hypothesis which states that random processes create the observed data. In these island models, the rate of population change is described by:

- where *N* is the total number of individuals in the population, *b* and *d* are the per capita rates of birth and death respectively, and *r* is the per capita rate of population change.[49][50]
- Using these modeling techniques, Malthus' population principle of growth was later transformed into a model known as the logistic equation by Pierre Verhulst:
    - population ecology builds upon these introductory models to further understand demographic processes in real study populations. Commonly used types of data include life history, fecundity, and survivorship, and these are analysed using mathematical techniques such as matrix algebra.
    - The information is used for managing wildlife stocks and setting harvest quotas.
    - In cases where basic models are insufficient, ecologists may adopt different kinds of statistical methods, such as the Akaike information criterion, or use models that can become mathematically complex as "several competing hypotheses are simultaneously confronted with the data."

Metapopulations and migration

- The concept of metapopulations was defined 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 models simplify the landscape into patches of varying levels of quality, and metapopulations are linked by the migratory behaviours of organisms.
- Animal migration is set apart from other kinds of movement because it involves the seasonal departure and return of individuals from a habitat.
- Migration is also a population-level phenomenon, as with the migration routes followed by plants as they occupied northern post-glacial environments.
- Plant ecologists use pollen records that accumulate and stratify in wetlands to reconstruct the timing of plant migration and dispersal relative to historic and contemporary climates.
- These migration routes involved an expansion of the range as plant populations expanded from one area to another.
- There is a larger taxonomy of movement, such as commuting, foraging, territorial behaviour, stasis, and ranging.
- Dispersal is usually distinguished from migration because it involves the one-way permanent movement of individuals from their birth population into another population.
- In metapopulation terminology, migrating individuals are classed as emigrants (when they leave a region) or immigrants (when they enter a region), 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; the population at the site will disappear unless rescued by an adjacent source patch or environmental conditions become more favourable. Metapopulation models examine patch dynamics over time to answer potential 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 are sources when conditions are more favourable. Ecologists use a mixture of computer models and field studies to explain metapopulation structure.

Community ecology

- Community ecology is the study of the interactions among a collection of species that inhabit the same geographic area.
- Community ecologists study the determinants of patterns and processes for two or more interacting species.
- Research in community ecology might measure species diversity in grasslands in relation to soil fertility.
- It might also include the analysis of predator-prey dynamics, competition among similar plant species, or mutualistic interactions between crabs and corals.

Ecosystem ecology

- Ecosystems may be habitats within biomes that form an integrated whole and a dynamically responsive system having both physical and biological complexes.
- Ecosystem ecology is the science of determining the fluxes of materials (e.g. carbon, phosphorus) between different pools (e.g., tree biomass, soil organic material).
- Ecosystem ecologists attempt to determine the underlying causes of these fluxes.
- Research in ecosystem ecology might measure primary production (g C/m^2) in a wetland in relation to decomposition and consumption rates (g C/m^2/y).
- This requires an understanding of the community connections between plants (i.e., primary producers) and the decomposers (e.g., fungi and bacteria),
- The underlying concept of an ecosystem can be traced back to 1864 in the published work of George Perkins Marsh ("Man and Nature").
- Within an ecosystem, organisms are linked 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.

- Ecosystems are broadly categorized as terrestrial, freshwater, atmospheric, or marine.
- Differences stem from the nature of the unique physical environments that shapes the biodiversity within each.
- A more recent addition to ecosystem ecology are technoecosystems, which are affected by or primarily the result of human activity.

Food webs

- A food web is the archetypal ecological network. Plants capture solar energy and use it to synthesize simple sugars during photosynthesis.
- As plants grow, they accumulate nutrients and are eaten by grazing herbivores, and the energy is transferred through a chain of organisms by consumption.
- The simplified linear feeding pathways that move from a basal trophic species to a top consumer is called the food chain.
- The larger interlocking pattern of food chains in an ecological community creates a complex food web.
- Food webs are a type of concept map or a heuristic device that is used to illustrate and study pathways of energy and material flows.
- Food webs are often limited relative to the real world. Complete empirical measurements are generally restricted to a specific habitat, such as a cave or a pond, and principles gleaned from food web microcosm studies are extrapolated to larger systems.
- Feeding relations require extensive investigations into the gut contents of organisms, which can be difficult to decipher, or stable isotopes can be used to trace the flow of nutrient diets and energy through a food web.
- Despite these limitations, food webs remain a valuable tool in understanding community ecosystems.
- Food webs exhibit principles of ecological emergence through the nature of trophic relationships: some species have many weak feeding links (e.g., omnivores) while some are more specialized with fewer stronger feeding links (e.g., primary predators).
- Theoretical and empirical studies identify non-random emergent patterns of few strong and many weak linkages that explain how ecological communities remain stable over time.
- Food webs are composed of subgroups where members in a community are linked by strong interactions, and the weak interactions occur between these subgroups.
- This increases food web stability.
- Step by step lines or relations are drawn until a web of life is illustrated.

Trophic levels

- A trophic level (from Greek *troph*, τροφή, trophē, meaning "food" or "feeding") is "a group of organisms acquiring a considerable majority of its energy from the lower adjacent level (according to ecological pyramids) nearer the abiotic source."

- Links in food webs primarily connect feeding relations or trophism among species.
- Biodiversity within ecosystems can be organized into trophic pyramids, in which the vertical dimension represents feeding relations that become further removed from the base of the food chain up toward top predators, and the horizontal dimension represents the abundance or biomass at each level.
- When the relative abundance or biomass of each species is sorted into its respective trophic level, they naturally sort into a 'pyramid of numbers'.
- Species are broadly categorized as autotrophs (or primary producers), heterotrophs (or consumers), and Detritivores (or decomposers). Autotrophs are organisms that produce their own food (production is greater than respiration) by photosynthesis or chemosynthesis.
- Heterotrophs are organisms that must feed on others for nourishment and energy (respiration exceeds production).
- Heterotrophs can be further sub-divided into different functional groups, including primary consumers (strict herbivores), secondary consumers (carnivorous 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 compared to herbivores, they are relatively inefficient at grazing.
- Trophic levels are part of the holistic or complex systems view of ecosystems.
- Each trophic level contains unrelated species that are grouped together because they share common ecological functions, giving a macroscopic view of the system.
- While the notion of trophic levels provides insight into energy flow and top-down control within food webs, it is troubled by the prevalence of omnivory in real ecosystems.
- This has led some ecologists to "reiterate that the notion that species clearly aggregate into discrete, homogeneous trophic levels is fiction."
- Nonetheless, recent studies have shown that real trophic levels do exist, but "above the herbivore trophic level, food webs are better characterized as a tangled web of omnivores."

Keystone species

- A keystone species is a species that is connected to a disproportionately large number of other 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.

- 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 led indirectly 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 difficult to experimentally determine what species may hold a keystone role in each ecosystem.
- Furthermore, food web theory suggests that keystone species may not be common, so it is unclear how generally the keystone species model can be applied

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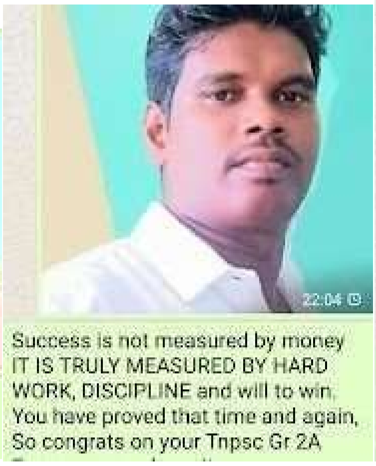

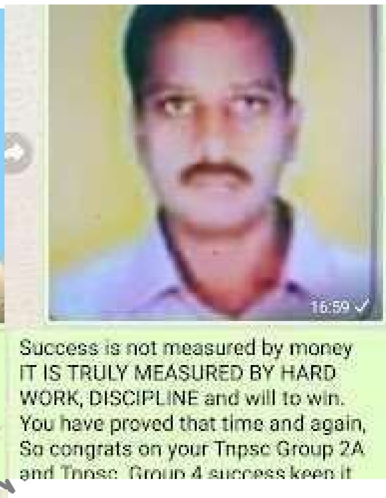

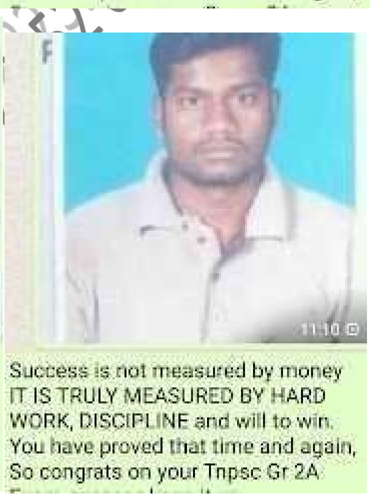

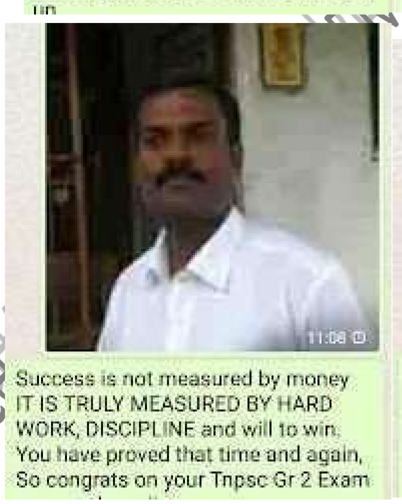


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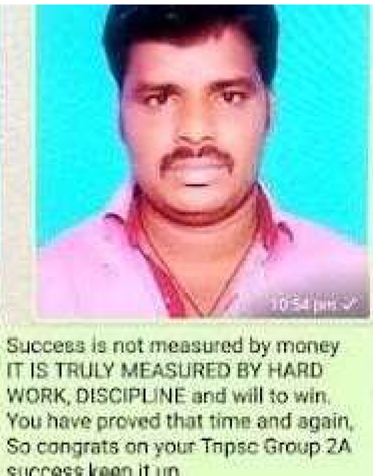
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