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Biodiversity and Ecosystem Services

Edvard O. Wilson once commented that although science has brought us precise answers to a range of exceedingly difficult questions, such as the number of stars in the universe, the masses of the earth and its neighboring planets, the number of genes in a virus, the mass of the electron, etc., we still do not know how many species of living organisms there are on earth – not even to the closest order of magnitude! This fact, which may appear surprising to many, has been a major motivation behind the rising interest in biodiversity the last 20 years. The term biodiversity itself is just as old, starting with a conference called the National Forum on Biodiversity in 1986 (Wilson 1988). Biodiversity is often represented as three hierarchically nested organization levels: those of genes, species, and habitats.

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Genetic diversity refers to the level of variability among genes with the same or similar function in a population of organisms. By a population we here understand a group of organisms capable of exchanging genetic material. Genetic diversity is the basis for the ability of organisms to evolve and adapt to changing environmental conditions. Thus, inbreeding and loss of genetic diversity often reduce the likelihood of population persistence. Relevant examples are found both in the management of large carnivorous mammals and in stocking programs for economically important species like the Atlantic salmon.

Species diversity is what most people probably conceive as the amazing diversity of life: the morphological and functional variability among living organisms, although the species concept itself can become technically complicated. The most common species definition is attributed to Mayr (1970) “groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups,” but this definition becomes less useful when considering non-sexually reproducing (clonal) organisms, such as bacteria and protists.

Habitat diversity refers to the variability of physical environments to which different living organisms are adapted. The preservation of intact living habitats is the major premise for species persistence. Or, put in other words, it is impossible to conserve a given species without also taking the preservation of its natural habitat into consideration. Habitat destruction and fragmentation is by far the greatest threat to all three hierarchical levels of biodiversity today. Particular concern is given to the ongoing destruction of biodiversity “hot spot” habitats like rain forests and coral reefs.

The distribution of known species among phylogenetic groups is probably surprising to many: the biochemically and morphologically diverse groups of bacteria and protists (unicellular eukaryotes) are also the most species-poor ones with fewer than 100,000 described species altogether. Fungi and higher plants constitute about 350,000 species, while metazoas (multi-cellular animals) are by far the largest group with about 1,320,000 described species. Part of this discrepancy is probably due to the amount of effort devoted to investigating different groups of organisms, although techniques of molecular biology are today making it easier to discriminate between species and reconstruct phylogenies (evolutionary trees) for unicellular organisms. But the most obvious biological explanation is probably the evolution of sexual reproduction in multi-cellular plants and animals and how this paves the way for rapid adaptation and inter-sterility barriers between morphologically similar populations.

These are the species that have been collected, scientifically examined, and classified. What we do not know is how many species there are that have not yet been described. Extrapolations to the total number of species are hampered by the fact that the earth has not been explored uniformly – northern temperate regions, especially in the vicinities of universities have been investigated far better than others. Potentially species-rich habitats like the high canopies of tropical forests or the deep oceans have been appreciably under-explored. Consider that 2/3 of the earth is covered by oceans, that the mean depth of the oceans is 3700 meters, and that most of marine biological research has been focused on the upper few 100 meters of this. So it is perhaps not surprising that current estimates of the number of species of earth range from 2 to 100 million.

There are several reasons to believe that species diversity is currently being lost at an increasing rate and that human activity is the main cause of this. Habitat loss due to clear-cutting, agriculture, and urbanization is generally recognized as the major determinant of biodiversity loss. As populations need a minimum habitat area to maintain themselves, habitat fragmentation due to construction of roads, power-lines, etc also contribute strongly to this trend. Many populations are also negatively affected by local pollution and over-exploitation. The latter is most evident for economically important fish stocks. Invasions by non-native (exotic) species are often also cited as a major threat to biodiversity, especially in connection with ballast water released by marine transportation. But there is an ongoing and unresolved scientific discussion on this: some scientists argue that species invasions have throughout geological time always led to increasing species diversity (e.g., Rosenzweig 2001). Rapid climate change due to emissions of greenhouse gases has also been identified as a potential threat to biodiversity; where the critical issue is to what extent species are able to migrate fast enough to escape local changes in climatic conditions (e.g., Thomas et al. 2004).

A lot of research effort is being invested into quantifying how fast biodiversity is being lost, what the consequences are of this loss, and if there are services that healthy ecosystems provide us with, which are diminished by loss of biodiversity. Ecosystem services (Daily et al. 1997) are processes by which the environment produces resources that we often take for granted. Such as: moderating weather extremes, mitigating drought and floods, protection from erosion, regeneration and preservation of soils, cycling and transport of nutrients, protection from the sun's ultraviolet rays, detoxification and decomposition of wastes, purification of air and water, dispersion of seeds, control of agricultural pests, regulation of disease-carrying organisms, pollination of crops and natural vegetation. For example, 80% of Mississippi River Valley wetlands have been lost by draining and channeling since 1940, leading to less capacity in the river system to absorb and buffer floods. The 1993 Mississippi River flood caused by lack of wetland buffering resulted in property damage estimated at 12 billion dollars. For example, 9 of the top 10 drugs used in the U.S. originate from natural plant products, and among the top 150 prescription drugs 87 originate from plants, 21 from fungi, 6 from bacteria, and 3 from vertebrates (snakes). For example, over 100,000 different animal species are involved in pollination of economically important plants (bees, butterflies, moths, beetles, flies, birds, and bats). One third of human food comes from plants pollinated by wild pollinators, making a value of 4-6 billion dollars per year by wild pollination services in the U.S. alone. These few examples illustrate that ecosystem services we take for granted can be of immense value to human existence and welfare.

We know way too little about how biodiversity loss can affect the integrity of these services. Stanford ecologist Paul Ehrlich has forwarded the Rivet hypothesis: compare an ecosystem to an airplane fuselage – it can stand a few rivets popping, but at the loss of a critical one the ability to remain flying is lost. Ehrlich's hypothesis is but one out of many competing ones concerning biodiversity loss and ecosystem integrity. The problem is that we do not know which one best describes the situation, and upon which of them we should base our decisions.

To take a step back; Darwin (1859) already had the intuition that "…if a plot of ground be sown with one species of grass, and a similar plot be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can be raised in the latter than in the former case …the truth of the principle that the greatest amount of life can be supported by the great diversification of life, is seen under many natural circumstances". In the other words, we should expect a diverse community to be more productive and stable than a monoculture.

This intuition remained unchallenged until the 1970s, when Robert M. May showed that mathematical models of ecological communities with many interacting species should actually be less stable and more prone to extinction than simple ones (May 1973). The shock of May's derivations led ecologists into a long discussion on how to actually describe stability in ecosystems (elegantly summarized by Grimm and Wissel 1997). In the last decade much effort has been devoted to empirical studies of relationships between species richness and ecosystem stability, productivity, and reliability.

The BIODEPTH project (Biodiversity and Ecosystem Processes in Terrestrial Herbaceous Ecosystems - http://www.cpb.bio.ic.ac.uk/biodepth/contents.html) involving large-scale field experiments in 8 European countries seems to have firmly established that there actually is a positive relation between species richness and several indicators of ecosystem function in grassland ecosystems (Tilman 1999). We still know little about how well these results generalize to ecosystem services in other habitats and on higher trophic levels. Given the accelerating loss of biodiversity on our planet and the indisputable values of ecosystem services to mankind, these should be key research issues for the future.

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