APPLICATION OF ECOLOGICAL KNOWLEDGE TO HABITAT RESTORATION

Hartmut H. Koehler
Center for Environmental Research and Technology (UFT), University of Bremen, Germany.

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Summary

Terrestrial habitats are our home: we live there and they offer us most of our food. The land's productivity is jeopardized by an increasing pressure on fertile land and concomitant degradation, requiring the assessment of the soil resource and the development of strategies for sustainable use, conservation and restoration.

Degradation and the need for erosion control were described as early 2500 years ago by authors of the Mediterranean region. In spite of these early warnings, the problem has increased and has become more and more a challenge to our living conditions, if not to our survival.

To organize the complexity and various aspects of degradation and its assessment, a theoretical framework is necessary. An intriguing approach is the concept of looking at ecosystems as interactive hierarchies (holarchies). Ecosystems are self-organized, their development is non-linear and has a high level of unpredictability within the constraints given, e.g. by the specific biome.

Theory supports arguments for restoration targets and explains the impossibility of restoring pre-disturbance conditions because of the irreversibility of ecological succession. Ecological succession is an ecosystem process which involves multiple scales in space and time, as is illustrated in this article with results from a long-term study. Appreciation of the successional sequence and of mechanisms as well as of life strategies of the organisms involved—including soil biota—are essential for restoration. High site specific biodiversity may be achieved by a mosaic of differently timed disturbances.

Reference is made to the UN Conventions to Combat Desertification (UNCCD) and on Biological Diversity (UNCBD). The UNCBD addresses three levels of biodiversity, which are discussed in the theoretical context. Biodiversity is an essential good and property of ecosystems. From the interactions within the system, ecosystem services result.

The assessment of these ecosystem features delivers essential arguments for the judgment of degradation and for approaches to habitat restoration. Although these scientific judgments can be generalized, it is the specific societal context which governs their valuation. This is acknowledged by the Ecosystem Approach of the UNCBD. It integrates ecosystem theory and societal needs as a strategy for the integrated management of land, water and living resources to promote conservation and sustainable use in an equitable way. The operationalization of the theoretical considerations and principles of good ecological restoration practice are illustrated in selected examples.

1. Introduction

"Restoration ecology is needed to provide concepts, theory and operational grounds to combat damages to the environment due to land usages detrimental to ecological resources" (Jacques Baudry in this Topic of EOLSS).

The largest part of the Earth is inhabited by organisms, either terrestrial or aquatic in the seas and in freshwaters. Although man inhabits only a fraction of this animated area we are dependent on the functioning of the biosphere as a whole in terms of, for example, global carbon and water cycles, oxygen, climate, food, and living space.

Any of these interlinked services is essential for the survival of man, being an integral component of the biosphere. A glance at the world’s food resources reveals the scope of the stewardship we have a mandate for. According to recent data from various sources, such as the United Nations Food and Agricultural Organization (FAO) and the CIA World Factbook, almost 40% of the world’s land area is agricultural (crops and animals), with about 11% being under cultivation (arable area).

There is considerable pressure on the land potentially suitable for agriculture, as the increasing degree of utilization shows. In South Asia, utilization of fertile land presently amounts to 94%, due to extension but also due to loss of fertile land by various sources of degradation. (Circumstantial details are given in great depth in *Encyclopedia of Food and Agricultural Sciences and Engineering Resources* of EOLSS.)

In a publication on *Issues and Policy Options for 2020*, Sara Scherr and Satya Yadav from the *International Food Policy Research Institute* (IFPRI) write in a 1996 publication: “*The Global Land Assessment of Degradation (GLASOD)…estimates that nearly 2 billion hectares worldwide (22% of all cropland, pasture, forest, and woodland) have been degraded since mid-century. Some 3.5% of the 2 billion total is estimated to have been degraded so severely that the degradation is reversible only through costly engineering measures, if at all. Just over 10% has been moderately degraded, and this degradation is reversible only through major on-farm investments. Of the nearly 1.5 billion hectares in cropland worldwide, about 38% is degraded to some degree. Africa and Latin America appear to have the highest proportion of degraded agricultural land, and Asia has the highest proportion of degraded forestland”.*

The data compiled by FAO and GLASOD reveal dramatically that not only fertile soil but also productive waters are limited resources, and that they are increasingly degraded by pollution of various kinds and habitat destruction (chemicals, physical impact, noise, light, etc.). Climate change is aggravating and accelerating the negative processes. Bearing this in mind, it seems to be an enormous task to secure enough food for an increasing population, which depends on the successful handling of the even more demanding effort to sustainably perpetuate our global life supporting system. This effort has to include wise management of the resources and a lasting endeavor to heal the exploited fragile skin of the Earth in an interdisciplinary approach, integrating various disciplines of natural sciences, advanced technology, economy, social and cultural sciences, and indigenous knowledge.

Cereals and vegetables take a share of more than 90% of the agricultural world production (FAO data for 2002). A study from 1990, published by Prescott-Allen and Prescott-Allen in the journal of Conservation Ecology, reveals that only 82 plant species contribute to 90% of the national per-capita supplies of food plants, and a much smaller number of these supply the bulk of the calories humans consume. These plants can feed us only as long as climate and soil fertility allow for productivity and as long as the plants’ genes are not deteriorated due to degradation of genetic diversity.

Soil fertility is an ecosystem service resulting from the interactions of those organisms, for which soil is the habitat. In contrast to the relatively small number of plant species providing the bulk of food, soil fertility depends on the wealth of species diversity the soils harbor. In a similar way as for the food perspective take in the preceding paragraph, arguments can be developed to prove the importance of biodiversity also for other services, such as carbon sequestration with its effects on global climate or the cycling and flows of water. However, these are additionally influenced by oceans and surface waters; for these the EOLSS offers specific Encyclopedias or themes on, for example, *Water Sciences and Resources* and *Marine Ecology*.

Within fifteen years (1990-2005), annual publication numbers of articles on restoration ecology rose from almost zero to nearly 400. This state of the art will be presented in the EOLSS Topic *Application of Ecological Knowledge to Habitat Restoration* with considerable new perspectives from the various authors. Ecological knowledge is a mandatory prerequisite for the understanding of habitat degradation and for the development of restoration strategies. However, habitat restoration requires a truly interdisciplinary approach, integrating ecology with technology and socio-economy, along with issues of globalization, cultural understanding and strengthening of partnership. Due to the importance of land for humankind sketched above, the topic is covered with a strong emphasis of terrestrial ecosystems.

When we consider the consequences of human-caused changes of habitats in a scientific approach, a historical perspective may help to understand the new dimension we are facing nowadays. Also, for an understanding of the ecological basics of restoration, the scientific framework needs to be clarified. This refers to theoretical considerations as well as to approaches and experimental design of field studies in the real world. Being equipped with these tools, the idea and the feasibility of ecological restoration can be addressed.

The title of this topic mentions "habitat restoration". In the following introduction, habitat is understood in the wider meaning of biotope or ecosystem and not in its strict sense of the place or type of site where an organism or a population naturally occurs. Restoration will be used in a rather colloquial way if not mentioned otherwise.

The articles of this Topic will elucidate in great detail selected fields of habitat restoration and will present examples to clarify the diversity of the problem and the multitude of approaches and objectives. Dynamics and scale, specific aspects of biodiversity and specific landscapes are addressed.

2. Historical perspective

According to an article by M. Williams from 2000 in the Journal of Historical Geography, almost 50% of the land mass of the post-glacial pre-agricultural world was covered by forests; now the figure is below 30%. Global deforestation has increased in modern times dramatically, due to lumbering in more and more remote areas with increasingly efficient technologies. Deforestation is always accompanied by nutrient mobilization from changes in microclimate and activation of soil processes, intensifying the potential for nutrient loss by leaching and erosion. Harvesting the trees further aggravates the nutrient export. Frequency and scale of logging as well as afforestation are set according to technical and commercial criteria. Most natural disturbances, such as fire, storms, landslides, avalanches, insect pests, etc., differ from deforestation in scale, frequency and intensity. They lead to complex mosaics in the landscape which shift over time. The communities have adapted to such disturbances and the soil may regenerate. For forests, the time scale of regeneration is in the range of hundreds of years. In some regions of the world, as in Europe, the regeneration potential of soil and vegetation allowed for an increase of forest cover in modern times (see Figure 1).

Figure 1. Regrowth of forest in a valley in the black forest (Germany). Left 1936, right ca. 1990.

However, this may be accompanied by changes and often by a loss of biodiversity, particularly in afforestation to commercial monoculture stands. In other regions, deforestation may be followed by soil degradation and erosion (loss of fertile soil). This is well documented for extended regions of the Mediterranean, where deforestation started more than 2500 years ago as a prerequisite for and a consequence of the classical cultures (for more details on forests see *Afforestation and Reforestation*).

Plato is one of the most prominent reporters of this environmental disaster, with a clear recognition of the importance of soil and climate and of direct and indirect effects (Critias, 360 B.C., translated by Benjamin Jowett, 1871): "*Such was the natural state of the country, which was cultivated, as we may well believe, by true husbandmen, who made husbandry their business, and were lovers of honor, and of a noble nature, and had a soil the best in the world, and abundance of water, and in the heaven above an excellently attempered climate. ... its mountains were high hills covered with soil, and the plains ... were full of rich Earth, and there was abundance of wood in the mountains. Of this last the traces still remain, for although some of the mountains now only afford sustenance to bees, not so very long ago there were still to be seen roofs of timber cut from trees growing there, which were of a size sufficient to cover the largest houses; and there were many other high trees, cultivated by man and bearing abundance of food for cattle.*

Moreover, the land reaped the benefit of the annual rainfall, not as now losing the water which flows off the bare Earth into the sea, but, having an abundant supply in all places, and receiving it into herself and treasuring it up in the close clay soil, it let off into the hollows the streams which it absorbed from the heights, providing everywhere abundant fountains and rivers, of which there may still be observed sacred memorials in places where fountains once existed. ... there are remaining only the bones of the wasted

body, as they may be called ... all the richer and softer parts of the soil having fallen away, and the mere skeleton of the land being left.”
Even in the historic days of Plato, the described disaster did not come unexpected: as early as in the sixth century B.C, environmental laws were issued in ancient Greece to reduce cutting down forests and grazing livestock on the hillside and promote cultivation instead, in order to prevent erosion (Solon, Pisistratus).

There are many more documents from roman times, when the demand for wood not only had to fulfill the needs of the navy, of the building trade, of the glass industry and of the mines, but also for luxury heating in households and baths. Consequently, wood had to be imported to Italy. Pliny (23-79) complains about the effects of the exploitation of nature for the future. The hunger of the arenas in Rome for exotic animals in considerable numbers, which became more and more rare and regionally extinct, had direct effects on biodiversity.

Deforestation, loss of soil, destruction of habitats for many species and exploitation of species up to extinction was not limited to the Mediterranean. Similarly, in other parts of the world cultural development led to deforestation and degradation, as for example in China, where signs of wood shortage appeared in the thirteenth century. The effects of deforestation, overgrazing and over-exploitation are long-lasting and pose severe problems to our modern societies.

They not only affect the resource wood, but, as Plato told us so clearly almost two and a half millennia ago, soil and water and biodiversity. Although the need for conservation and sustainable use was recognized by the Greek statesmen mentioned above, measures have not been developed and followed adequately since then. We become aware that not only the region and culture we belong to is affected, but that this failure is challenging the life support system on a global scale.

In modern industrial times, machinery is capable not only of destroying but also of replacing whole landscapes, as in open cast mining (see Figure 2). Laws have regulated the reclamation of these anthropogenic landscapes, for example in Germany since the mid eighteenth century, in order to fulfill various overall objectives, such as heap and berm security, forestry, agriculture, recreation, etc. Site stability and technological feasibility have top priority, followed by water-related aspects and follow-up use.

Landscape architecture and landscape ecology are increasingly considered, but general ecological principles and issues of nature protection and biodiversity are only now beginning to influence the approaches. Extensively managed anthropogenic biotopes are increasingly valued as refugia for species and as dynamic sites, harboring high biodiversity.

As exemplified in Figure 2, reclamation may create extensive new landscapes. Monotony characterizes the agricultural and forestry substitute, whereas a mosaic of habitats and high biodiversity is achieved with a varied relief and the acceptance of natural succession (for more details see *Alternative Restoration Strategies in Former Lignite Mining Areas of Eastern Germany*).

Figure 2. Open cast mining (brown coal) in the Cottbus district (Germany). Left active mine, right artificial agricultural landscape on former mining area (top) and habitat rich reclamation (bottom).

3. The theoretical framework

Ecology as a science has a well defined terminology. Also, the use of terms of relevant UN conventions as developed in the Agenda 21 process should be taken into account (UNCBD, UNCCD, UNFCCC).

The definitions in these documents have been elaborated by a body of consulting scientists, are widely accepted and have legal relevance. Even in cases, where they may not fulfill specific requirements or views, they should be considered and critically reviewed, if necessary.

3.1. The holarchic concept of the biosphere

The biosphere may be analyzed as a nested hierarchy, from genes to ecosystems, biomes and the biosphere. In his book *The Ghost in the Machine* Arthur Koestler proposed the term holarchy to emphasize its interactive nature and the dualism of its constituents, the holons, which have integrity and identity at the same time as they are part of a higher unit.

Holons can be seen Janus-faced, one side acting autonomously, giving directions and constraints to lower levels, and the other side being receptive to and being part of the upper levels. The levels of the holarchy of the biosphere are shown in Figure 3.

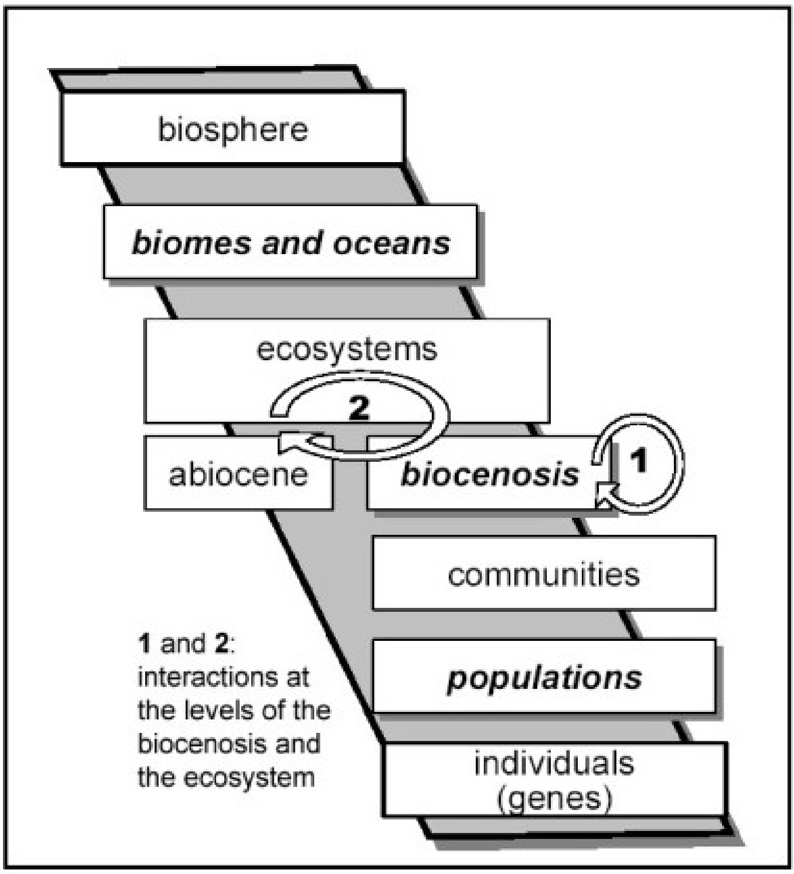

Figure 3. The holarchy of the biosphere.

It must be borne in mind that all levels except genes, individuals and the biosphere are defined according to specific rules. Interactions occur within each level, but as the holarchy implies, the whole biosphere is an interdependent unit, divided into levels for analytical purposes. Species identifications on the basis of the phylogenetic system (taxonomy) allow an immense differentiation of the individuals of a community or of the biocenosis of a site, supported and refined by genetic methods.

With the recognition of the interactive holarchic character of the biosphere, insights from the theory of complex systems can be applied, for example at the ecosystems level, such as self-organization and emergence of properties. It was Charles Darwin who challenged the static perception of, for example, Linnaeus (*Systema naturae*) and stressed the dynamics of nature. In self-organizing systems, these dynamics are historical (singular in time, irreversible), non-linear and co-operative, and ruled by constraints which are set by the holarchic context.

Compared to the higher level, the interactions occur at smaller scales (more rapid, less spatial extent) at the respective lower level. This becomes evident in landscape dynamics, which integrate over wide spatial and temporal scales (for details see *Landscape Dynamics*). At relatively higher levels properties emerge, which cannot be found at the lower level. For example, nutrient cycling on land is accomplished by plants and soil biota and involves abiotic sources and sinks. This process can be found neither on the level of biocenosis nor on that of the abiocene, but at the ecosystem level.

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Biographical Sketch

Hartmut H. Koehler was born in Würzburg, Germany, in May 1951. He studied at the German Universities of Erlangen, Göttingen and Bremen and at the University of California, Santa Barbara, USA. He finished his studies in biology and chemistry at the University of Göttingen and received his doctorate and his habilitation at the University of Bremen. He holds a professorship ("außerplanmäßiger Professor") in ecology at the University of Bremen.

For more than 30 years he has been involved in teaching at universities and professional schools. He started his research in the context of the International Biological Program (IBP, Solling Project, Göttingen) on the role of two species of Carabid beetles in the Solling beech forest ecosystem. Later, he focused on fauna living in the soil and on applied issues of succession, degradation, restoration, ecotoxicology and agriculture. Recent projects focused on long-term succession, phytoremediation, biodiversity and re-establishment of holm-oak (*Quercus ilex*) forest in the Mediterranean. He has published more than 90 papers, edited a book (Bodenökologie interdisziplinär, Springer, Berlin) and is a peer-reviewer for several journals. As a member of a number of scientific organizations and as a deputy board member of the German competence network Desert*Net, he is involved in the recent advancements of ecology and its applications.

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