ECOLOGICALLY BASED STANDARDS

Luc Hens
Department of Human Ecology, Free University of Brussels (VUB), Belgium

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Contents

Summary

As nature protection and environmental quality of ecosystems have gained importance as targets for environmental policy, policy makers are gradually becoming more interested in instruments to support this aspect of their action. Ecological standards are among these instruments.

This article describes the basic principles of ecological standard setting. These standards should relate to the emergent characteristics of ecosystems as biological networks. Ecological standards should address the structure and functioning of ecosystems. An important practical issue for policy makers is the classification of ecosystems, on which

the scientific discussion is ongoing. Related to defining ecosystems is the determination of their borders. These often have no clear demarcation lines but rather gradual transition zones.

Ecological standard setting is to an important extent based upon information provided by ecotoxicological experiments. Most data are available from single species assays. In these tests the toxicity of one or more pollutants on a selected species is determined. The toxicity is expressed as LD_{50}/ LC_{50} or NOEL/NOEC values. Experimental set-ups for both chronic and acute exposure exist. Values can be determined for indicator species in air, water and soil.

Organisms, insects, fish, worms or plants can be used as tests. The main limitation of single species assays is their reductionistic nature which alienates them from the complexity of the ecosystem. This problem can be alleviated in experiments with model ecosystems and in field observations. Models exist which allow for the extrapolation of single species assay data to an ecosystem level, but they cannot take into account all emergent ecosystem characteristics, as no data exist for most of them. Integrated risk assessment offers a coherent framework for the optimal use of all available data in ecological standard setting.

A synoptic overview of the principles underpinning surface water management in the Netherlands is presented to show how rather complex ecological standard systems can be used in practice.

Ecological standards today are less well established than health related standards. However their use will increase in the future. To this end an important amount of well targeted research will be necessary to erode the scientific uncertainty which is linked to the understanding of complex ecosystems.

1. Introduction

The focus of environmental policy has gradually shifted over the past fifty years from the protection of human health to the protection of the environment and the safeguarding of environmental quality. The philosophical reason underpinning this move is both ecocentric and anthropocentric. The concept gains impetus in that the environment has sufficient intrinsic value to be the main target of environmental policy. Biodiversity, ecosystem conservation and nature protection should be carried out, not because of human interest, but just because these goals as such are worthy of environmental policy and management.

In addition, there is the anthropocentric argument which shows that there are more and more diverse environmental functions and effects to be addressed than simply the protection of human health alone; how to deal with resource supply? with the aesthetic value of the environment? with its educational value? Moreover as pollution increased, it became more and more obvious that the wellbeing of humankind depends heavily upon the protection of environmental functions like the stratospheric ozone layer or an acceptable biological quality of surface water and the seas.

For all these reasons environmental policy should address environmental quality and should aim at keeping environmental functions and ecosystems intact. Standards can help to realize these goals and should be targeted towards such aims. This type of standard is called an environmental or ecological standard.

This article analyses the background knowledge and the basic principles underlying the establishment of ecological standards. It provides an example of water management and comments on prospects of this environmental policy instrument. It does not enter into the details of the methods used to establish ecological standards, as this is the subject of article Types of Standards.

2. Definition

There is no unique definition of an ecological standard, but one that describes its main concepts is: an ecological standard is an environmental quality standard addressing the protection of ecosystems.

A first issue raised by this definition is the seeming equivalence of the words "ecological" and "environmental". "Ecological" has different meanings in scientific literature:

- based on data provided by the scientific discipline of ecology;
- related to the characteristics of ecosystems;
- targeted towards nature and/or nature conservation;
- targeted towards the broader environment (including nature) and environmental quality;
- targeted towards the protection of (parts of) ecosystems.

These different meanings of "ecological" are not exclusive, but rather complementary. Environmental refers to the supporting matrices of life: water, earth, atmosphere and climate. It is however important to notice that the environment not only consists of dead material but also of living elements and their relationships.

In policy matters ecological is often preferred over environmental when ecosystems are concerned. This is the case when it is about ecological standards. It is however clear that "ecological" should be understood according to the broad interpretation which is present in the last two meanings indicated in the list above.

In contrast to standards aiming at protecting human health or at technical standards, ecological standards hardly exist today. However a lot of effort is being undertaken to establish them.

3. Background information

Ecological standards address the structure and functioning of ecosystems. They therefore should be based on a sound knowledge of the key characteristics of ecosystems. This section deals with three basic aspects of ecosystems which are important in ecological standard setting: relevant characteristics, borders and classification.

3.1 Characteristics of ecosystems relevant to ecological standard setting

Ecology studies (the network of) reciprocal relations between organisms and their biotic and abiotic environment. The spheres of interest of ecology range from individual organisms, through populations, to communities and ecosystems. These latter are functional units in which the biological, physical and chemical components of the environment interact.

In this discussion it is important to make a distinction between characteristics which belong to the ecosystem (emergent characteristics) and those which belong to its components (non-emergent characteristics). Species diversity and food web relationships are examples of emergent characteristics; biomass and chlorophyll content are examples of non-emergent characteristics.

Ecosystems are to a large extent characterized by two main emergent characteristics:

- relationships among the constituting components
- regulation of the system

The relationships to be studied concern the relationships between organisms (e.g. a food web), the relationships between organisms and their abiotic environment (e.g. O_2 exchange), and the relationships between the components of the abiotic environment (e.g. air-water exchanges). The more important the regulation at ecosystem level, the more important are these relationships.

In an ecosystem regulation exists at different levels: at the cellular level, at the level of organs and organisms (individuals), at the level of populations, at the level of communities and in the ecosystem as a whole. At each of these organizational levels different mechanisms and types of regulation act. At the cellular level, the DNA controls the genetic background; organs and organisms as a whole can be controlled by nervous and endocrine systems; populations are regulated by mechanisms such as adaptation, competition or cooperation.

To set ecological standards a thorough knowledge of the structure and the functioning of ecosystems is necessary. Ecological standards should avoid addressing fragmentary components of ecosystems. They should rather be designed to address complete ecosystems in both their emergent and non-emergent characteristics. Involvement of regulation and relationships is essential.

It is more important to consider the ecosystem as a whole than the individual components. An ecosystem from which a number of individuals disappear will recover easier than an ecosystem where populations have disappeared.

3.2 Typology and classification

Ecological standards, as a rule, are developed for (types of) ecosystems. Therefore a practical and scientifically sound classification of ecosystems is essential while setting ecological standards.

There is hardly any doubt that there are major differences among ecosystems. Terrestrial and aquatic systems differ; the tropical forest differs fundamentally from the savanna and the desert; different sets of plants and animals are found in sandy areas rather than in clay soils.

Structure and functioning of ecosystems are determined by abiotical factors, which differ from place to place. Therefore ecosystems are actually unique, in the same way that organisms and individuals have a unique genetic background. However, it is not practical to develop ecological standards for each individual ecosystem.

A classification of ecosystems is therefore necessary. To do this one should agree upon the classification criteria. At this moment there is no unequivocal system to classify ecosystems. Rather there are different systems which are all characterized by their own problems and advantages. Box 1 illustrates this using the example of three components of biodiversity: ecological diversity, organismal diversity and genetic diversity. They all have a hierarchical nature and overlap.

An important criterion is scale. Biomes subdivide the world as a whole in a reasonable number of areas with main biological differences such as the ones between savannas and deserts, Mediterranean systems and taigas. Next to biomes, much finer classifications are possible, such as ecoregions, ecodistricts, ecosections, ecoseries, ecotopes, and ecoelements. Of all these, ecoregions (based upon abiotic, geological and geomorphological criteria) and ecodistricts (involving morphological, climatological, geological and hydrological borders) are the most practical levels to be used in ecological standard setting.

Ecological diversity	**Genetic diversity**	**Organismal diversity**
biomes		kingdoms
bioregions		phyla
landscapes		families
ecosystems		genera
habitats		species
niches		subspecies
populations	populations	populations
	individuals	
	chromosomes	
	genes	
	nucleotides	
Cultural diversity: human interactions at all levels		

Box 1. The composition and levels of biodiversity

Next to scale, function is important. Classical zoning maps use a subdivision into natural, agricultural, industrial and urban areas. Ecological standards might set differential quality levels for these different zones although the biological quality in an industrial zone might be influential for the quality in the neighboring, downstream nature reserve.

Different classifications exist on the basis of abiotic parameters. For water, a subdivision in fresh, brackish and sea-water seems obvious. For soil, different, more complex and refined classification systems exist. The main question is to which extent do these classifications provide information on the ecosystems they house?

Research in this area has been strongly supported during recent years by the development of geographical information systems (GIS). A GIS is a computer database which can bring together spatial, thematic, statistical and image data using the concept of superimposed data layers.

Data layers can be combined to produce composite images, identify combinations of data elements, perform statistical analyses or generate classifications. In simple terms this technology gives the user the ability to enter, display, edit and manipulate computer-stored information in a geographical, or spatial context. In a general sense GIS could be considered a high-order map.

This evolution has made the development of ecological information systems possible. They entail the basic information (both biotic and abiotic) which is necessary to characterize ecosystems. They equally entail information which allows interpretation e.g. of the sensitivity of ecosystems or the degree to which they are threatened.

An important related field is the study of land use changes. These studies, which are often based on GIS studies using satellite and/or aerial photographs, show that in densely populated and newly developed areas, the use of the soil, and consequently the ecosystem, changes at dramatically high rates. In the area around Halong Bay (North Vietnam), the land use in the bay area, bordering the UNESCO World Heritage Site of over 3000 small karst islands, providing a unique seascape, changed by 66% from 1983 to 1996, mainly as a consequence of aquaculture development.

Moreover, during the last years of the decade a new port area was developed. In Chapare (Bolivia)—a tropical forest area marked by authorities as an area to be developed—55% of the virgin forest disappeared between 1990 and 1998, to be replaced by agriculture. Land use changes show that ecosystems change under human influence, sometimes dramatically. Ecological standards need to take this element of dynamics into account.

3.3 Borders of ecosystems

A particular problem in the definition of ecosystems concerns their border(s). Borders are often difficult to define in the sense that they are not often characterized by abrupt changes, but rather by gradual transition zones, e.g. between soil types, or between brackish and fresh water, or as a gradient of humidity. These transition areas can vary from very small up to sizes expressed in square kilometers.

In these border areas conditions change and consequently ecosystem characteristics such as species distribution and food web relationships also change. Ecological standards have to take these aspects into account.

4. Basic principles for ecological standard establishment

The scientific discipline of setting ecological standards is termed ecotoxicology. This subject area is concerned with understanding where anthropogenic chemicals go into the environment (their fate) and hence the extent to which ecological systems are exposed to them (their exposure) and, in consequence, the ecological effects they have (effects). Simply phrased, ecotoxicology provides information for setting ecological standards as toxicology and epidemiology do for setting human health standards.

Analogously to epidemiology, ecotoxicology is increasingly used as a basis for environmental risk assessment in the development of environmental protection legislation. Therefore it is important to understand the basic principles of ecotoxicology which are relevant for setting ecological standards. These paragraphs provide a definition and an overview of the most frequently used tests and systems in ecotoxicology.

They entail single-species tests, tests on modeled ecosystems and field investigations. The interpretation of the data necessitates, however, an integrated risk assessment framework which provides a coherent interpretation of the available data. The rationale underlying this approach is described in the last section of these basic principles.

4.1 Definition and scope of ecotoxicology

Ecotoxicology studies the toxic action of agents in ecosystems. The agents which are studied are mainly chemicals (e.g. pesticides) or physical agents (e.g. ionizing radiation). Ecotoxicology combines methods from toxicology, ecology, chemistry and physics. Therefore ecotoxicology is a multidisciplinary/ interdisciplinary subject.

For ecological standard setting it is important for ecotoxicology to go beyond the study of effects on individuals, or groups of individuals belonging to one species. An important target is the study of the ecosystem including relationships among species and relationships between species and their abiotic environment. Ecotoxicology is characterized both by fundamental and applied research. For standard setting the results of the applied research experiments are of primary importance.

4.2. Single-species tests

Single-species tests aim at studying the toxicity of one substance or a combination of agents using one species of the ecosystem. The principles underlying this type of ecotoxicological experiments are very similar to those in human toxicology, measuring the toxicological effects of a medical drug on an experimental animal. One must deal with similar problems such as the choice of the parameter(s) of toxicity, effects studied, exposure time, route of exposure, background concentrations and the ethical (use of living organisms in experimental setups) aspects. However, ecotoxicity tests also show specific aspects, which include: the choice of the species to be tested, exposure time, toxicity parameters and the extrapolation of the data at an ecosystem level.

4.2.1 Test organisms

Choosing test organisms is closely related to the environmental compartment for which standards need to be established: fish to measure the ecotoxicity in water, worms for soil and lichens to measure air pollution. Moreover, to set a standard, data on different species should be available. The selection of this number is limited by practical considerations as it is impossible to test all organisms in an ecosystem. The issue is important as ecotoxicity parameters can significantly differ among species. This applies, for instance, to core parameters as the letal concentration for 50% of the group (LC_{50}) and the highest concentration of a substance to show no statistical difference from the control in an observed variable (NOEC). Ragas et al. (1994) publish LC_{50} values for cadmium in soil which range from 2 μg/kg to 32000 μg/kg for different species; NOEC values range from 0.15 μg kg^{-1} to 6000 μg kg^{-1}. For lindane the corresponding ranges are for LC_{50} 3 to 4600 μg kg^{-1} and for NOEC 2.2 to 1000 μg kg^{-1}.

A particular discussion concerns the use of “the most sensitive species”. Some experts suggest that the most sensitive species is the most efficient indicator for toxicity. Although there is a good deal of intellectual attractiveness in this argument, there are also a number of mainly practical limitations. Suppose e.g. the sea lion or the orca is the most sensitive species; should one then set up an experiment exposing sea lions and (sometimes rare) marine mammals? The most sensitive species is often unknown. Field experiments aiming at identifying the most sensitive species are laborious and expensive.A partial alternative to this discussion is offered by the use of test panels. These fixed combinations of test species offer a number of practical laboratory advantages and provide the possibility to compare data. Their main disadvantage is that they are not or are to a very limited extent, ecosystem specific.

4.2.2 Exposure time

The exposure time is the period during which a chemical or physical agent is in contact with the biological test system. To a large extent discussion on exposure time in ecotoxicology is similar to the discussion in human toxicology. In a nutshell: acute exposure is relatively easy to realize and to evaluate, while chronic exposure offers more difficulties, but is closer to reality.

The weight of this argument is important in ecotoxicology as acute exposure only occurs in accidental and disaster situations. As chronic exposure is very prevalent in nature, even when the experiments are more costly and time consuming, it is the indicated approach to establish guidelines. In practice, exposure time can sometimes be shortened, using embryonic and larval stages of organisms which are more sensitive than adult lifeforms.

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Biographical Sketch

Professor Luc Hens obtained his Licentiate in Biology from the Free University of Brussels (VUB) in 1974, Aggregation of Higher Secondary School Teaching from the VUB in 1975, and PhD from the Faculty of Science of the VUB in 1981.

Professor Hens is a member of several professional societies and recipient of a number of honours and awards, including the prestigious award of the Belgian Royal Academy of Sciences and Arts which he was awarded in 1984. Currently he is the Head of the Department of Human Ecology at the VUB.

He has been responsible for organising and/or participating in several international research and postgraduate teaching programmes in many countries including Bolivia, Bulgaria, Brazil, Brussels, the Czech Republic, Ghana, Hungary, Turkey, the Ukraine and Vietnam.

To date the publications of Professor Hens number about 200 including twenty-six books. He is also the co-editor of the journals *Environment, Development and Sustainability* and *Environmental Pollution.* His teaching and research interests include environmental management, sustainable development, human ecology, and related issues.