Assessment of Wild Biodiversity in Agricultural Land Use

First design and perspectives of a pressure-based Global Biodiversity Model

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1. Introduction

Biodiversity was one of the main issues at the World Summit on Sustainable Development in Johannesburg 2002. The world target set by its members is to a significantly reduce biodiversity depletion by 2010. Agreements on how to measure biodiversity and establish a core set or framework of biodiversity indicators was at the time unattainable in such international forums as the Convention on Biological Diversity (CBD). Although the assessment of future trends of biodiversity − generally focused on terrestrial natural ecosystems and possible effects of policy responses − is difficult, several initial tools in this field, including the GLOBIO model and the Natural Capital Index (NCI) framework, were presented in Global Environment Outlook 3 (UNEP 2002; UNEP in press). The situation in (intensively) managed agricultural and livestock production systems has been virtually "untouched", although it is considered a major topic. An Internet search by ULRMC has shown, however, that the agriculture− biodiversity issue in Europe tends to be rapidly gaining in prominence on the research and debate agenda, advancing from 25,000 hits in 2001 to 166,000 hits by April 2003. It cannot be denied that livestock production in cultural landscapes always severely damages biodiversity when seen in the framework of the original natural ecosystems; however, remaining biodiversity in cultural landscapes should not be undervalued.

Four main arguments have been presented to show the need to assess the conditions for and trends of wild-plant and animal species in cultural landscapes. The *firs*t one is the conversion of a significant share of terrestrial ecosystems (about 50% of all European land). *Secondly*, many species, including rare species threatened with extinction, depend on adequate management of cultural landscapes. *Thirdly*, cultural landscapes are highly valued by the population (see, for example, the Ukrainian open fields with cereal crops and the hedges

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around farmlands in England, some of them already protected (UNESCO cultural heritage sites). *Fourthly* and finally, a policy change has recently occurred in which the biodiversity conservation strategy of protection was translated into sustainable use. We expect that possibilities will arise from the assessment of biodiversity in cultural landscapes to reduce the negative impact or maintain a significant share of biodiversity along with sustainable use.

The National Institute for Public Health and the Environment (RIVM), work together with the United Nations Environmental program (UNEP) World Conservation and Monitoring Centre (WCMC) and UNEP GRID Arendal to address both natural and cultural ecosystems, and terrestrial as well as aquatic and marine ecosystems. Based on their experience on biodiversity assessment, an international consortium has been founded to build new tools for the assessment of current state and future biodiversity trends. The Ukrainian Land and Resource Management Center (ULRMC) is one of the four pilot counterparts at the national level participating in the two-year GEF funded CBD-WCMC project, "Biodiversity Indicators for National Use" (BINU). The objective of the project is to assess trends in Ukraine agrobiodiversity.

The focus in this paper is on modelling biodiversity of wild-plant and animal species in agricultural and livestock production landscapes. Not included are the genetic diversity of domesticated animals and food crops, or ecosystem (landscapes) diversity. Biodiversity that directly supports production (for example, soil-quality related species or insects being pollinators or pest controllers) is considered here to be an integral element of wild biodiversity. For this reason, we did not follow the functional biodiversity approach of the OECD Agri Biodiversity Framework (ABF), but took another recommendation into account, i.e. the classification of production systems into low-to-high intensity or into semi-natural-to-completely modified ecosystems. According to the suggestions of the Millennium Ecosystem Assessment (MA), assessment should include analysis on different scales (landscape, national, regional and global).

This paper presents the very first insights into and tools used in building a new Global Biodiversity Model (GLOBIO), which can also be used for assessments of agricultural land use and landscapes. This model also represents an initial attempt to combine information, stimulate discussion, promote exchange of knowledge and joint learning, and improve conceptual thinking. It provides us with the first grasp on application and encourages scientists and politicians to focus on biodiversity maintenance as an integral part of the production function. It also presents the GIS software that will be used for interactive communication on different scales.

2. The process of biodiversity depletion

The rate of biodiversity loss has accelerated rapidly, especially during the last century. UNEP and international nature-protection NGOs have published data that indicate extinction rates of plant and animal species a thousand times the natural rate. However, extinction is the final step in a long and complex process of ecosystem degradation, a process characterised by the decline of abundance and distribution of many species and at the same time an increase in abundance and distribution of a few others. A few common species are becoming more common, many rare species more rare. This is what we call the uniformity process (Ten Brink et al. 2000; Ten Brink 2003; RIVM 2002).

Biodiversity depletion has two main causes (UNEP/CBD 1997; OECD 2001b): a) loss of habitats (size of ecosystem surface) and b) loss of ecosystem quality (decreasing abundance of many characteristic species). The natural ecosystem area frequently changes because of land (-use) conversion into agricultural land. Decreasing ecosystem quality is generally caused by such factors as:

- climate change, pollution, habitat fragmentation, and over-exploitation in natural and cultural ecosystems and
- intensification of the production system, the use of external synthetic inputs (pesticides and fertilisers), commodity specialisation at farm and regional level and irrigation.

However, marginalisation of natural resources is also a cause, for example, the water-induced soil erosion in historical landscapes of upland or mountain ecosystems. The European Environment Agency (EEA) and UNEP warned recently that the degradation of Europe's vital soil resources and desertification would continue and even accelerate unless prompt action is taken now. Quantity and quality have become two main pillars of the proposed indicator framework linked to the Global Biodiversity Model.

3. Model development

The challenge is to create a model and indicators that are able to describe the above process of biodiversity depletion for meeting policy requirements on different geographical scales (national and global). We have followed the April 2003 recommendations of the CBD expert group on biodiversity indicators: **"**to pay attention to species distribution and abundance data as optimal building blocks for the model, to classify information into quantity and quality data, and to aggregate species information into species-assemblage trend indices for specific species groups and into a sort of Natural Capital Index for the condition and trends of ecosystems**"** (personal communication of Ben ten Brink, expert group member for the Netherlands). These recommendations have become the logical bridge between indicator development and global modelling.

The Global Biodiversity Model makes use of indirect–direct pressures, and the state and response (PSR) indicator framework (OECD 2001b). "State" is then further defined as the "abiotic conditions on which species depend, plant and animal species that live and reproduce (biodiversity) as well as the goods and services that are provided by biodiversity". According to the European Centre for Nature Conservation (Wascher 2000), agricultural practices (technological applications) are considered as direct pressures changing the (abiotic) environmental state and thus biodiversity. Indirect pressures are agricultural processes such as abandonment, marginalisation, intensification, urbanisation, and socio-economic and political processes.

The model represents, in fact, a framework of many existing models (e.g. IMAGE 2.2, see Alcamo et al.1998) and several new ones. The core business of the Global Biodiversity Model will be to assess biodiversity from effects of environmental and habitat changes. The model will be linked to pollution**,** climate change models, demographic models, land-cover and land-use models and other factors. The objective of the model is to assess the impacts of environmental change and other human pressures on species, ecosystems, biodiversity and ecosystem services. The framework can also be used for evaluating possible policy strategies.

The design of the model is based on a process approach. It is a generic model, applicable to species, species groups, ecosystems and pressures on biodiversity. Here, the process does not indicate an experimentalist approach but, rather, a dynamic understanding of interactions and ecological processes. The model also links impact on species with impact on biodiversity at ecosystem level on the basis of rule sets of different pressure – impact relationships. Socio-economic modelling is outside the scope of the model.

The focus in this paper is on the rule-based short-cut for extensively or intensively managed agricultural livestock landscapes. The rule-based approach is chosen because we expect a lack of data on a global scale for most species data. General dose–effect relationships, derived from the literature, can fill the gap through use in regional assessments and "what-if" evaluations. This short-cut can be applied in quick assessments and for exchanging information and results between national and international levels. Data flow in the pressure-driven Global Biodiversity Model is shown in Figure 1.

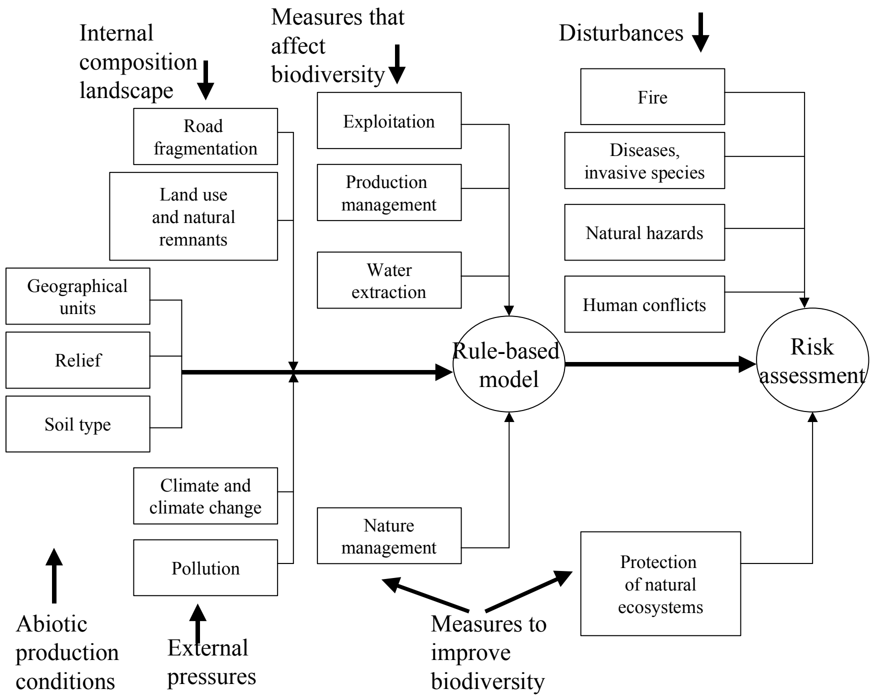

Figure 1: Visualisation of data flow in the pressure-driven Global Biodiversity Model.

4. Application to agricultural-livestock landscapes

Several types of pressure and nature management schemes in combination with production or exploitation, as visualised in Figure 1, will be reviewed here for their relationship to biodiversity. We should mention at the outset that the dose–effect relationships are not yet available. Rather than a quantification of possible effects the relevant factors have on biodiversity, one can expect to find here the scope of factors overviewed, the position these effects hold among the factors and the availability of data. Other (additional) factors may play a role on a local scale. Here, only some of the relevant factors on the global scale are presented.

All information relevant to the "pressure-based" biodiversity assessment in cultural landscapes can be derived from the following research questions:

1. Which relevant land uses (global scale), landscapes (regional to national scale) and production systems (local to national scale) can be distinguished?
2. What are the actual abiotic production conditions? To what extent are environmental conditions unsuitable for production (soil and climate conditions)?
3. What kind of natural remnants (tree compositions and water bodies) can be found in cultural landscapes? To what extent is the landscape fragmented by road infrastructure?
4. Which external factors influence production and biodiversity?
5. What are the relevant management techniques in production systems affecting biodiversity locally and regionally, and what are the dose–effect relationships of agricultural management on biodiversity?
6. What are the effects on biodiversity when different levels of limitation to the application of technology are compared (conventional, integrated management, organic farming)?
7. What are disturbances to production systems and to related biodiversity in cultural landscapes?
8. What are the trade-offs between agriculture and protected areas?

We extracted important information from the Food and Agriculture Organisation (FAO), the OECD (2001b) and the EC (Hoffmann 2000) on factors to help us understand the relationship between agricultural-livestock production and wild-species biodiversity. We have grouped the factors according to their relationship to biodiversity, and added some sources for the available worldwide databases and maps.

Abiotic characteristics

No (global) assessment is possible without geographical classification according to general features of the natural resource base. Abiotic characteristics of the land may be soil type, altitude and slope. These indicate the quality of the land, which will allow land degradation to be foreseen and suitability of the land for agricultural-livestock production to be ascertained (selected maps and models, e.g. FAO soil map of the world 1995; IMAGE 2.2 land use and climate change model; GLOBE DEM 1 km elevation).

Land-cover types

Many efforts have been taken to classify the world into land uses or land-cover types. Several disciplines worked together in order to define where forest, agriculture, extensive grassland and other natural ecosystems are located (GLC 2000 dataset; Ecological zones in IMAGE 2.2). We need to know the size of land use, landscapes and production systems today and to what extent each affects wild biodiversity. In the same way as biodiversity is assessed in natural ecosystems, the change in both area size and system quality will be assessed for agricultural uses or landscapes (Ten Brink 2002).

Nature remnants

Landscape quality cannot be determined in a straightforward manner from effects of a production system alone. Landscapes consist of a mosaic of production fields, grassland and forest patches ("green" terrestrial natural remnants), natural water streams and locations with unsuitable production conditions. Natural remnants provide ecological structures for food, nesting and shelter for plant and animal species.

Major land-cover types have, therefore, been analysed for composition of different land uses (e.g. farming systems, FAO data), natural elements (e.g. trees, cultivated fields, freshwater systems) and fragmentation by road infrastructure. ULRMC recently showed that Remote Sensing data could be useful in determining landscape structures and or natural remnants in agricultural land-use areas. ULRMC observed lower surface temperatures at night in protected areas than in agricultural areas. This unexplained observation still indicates, however, important future opportunities for inexpensive methods in the analysis of land-cover mosaic patterns with frequent observations (time series).

External pressures on agroecosystems

Several external pressures from outside agricultural production systems such as climate change and pollution from urban areas and industry affect biodiversity. Information on underlying (general) drivers of biodiversity depletion like GNP, technology, poverty and/or human population density may also be used to show that indirect pressures exert a negative impact (Some pressures can be calculated with IMAGE 2.2).

Land use and production management

It is possible to obtain further insight into direct production-related pressures from an overview of the (crop and animal) production technology at farm level, as well as exploitation systems in (semi-)natural ecosystems in general (hunting, fishery, grazing) (IMAGE 2.2). Production systems have different impacts on biodiversity because they are constructed from specific packages for management practice, e.g. pesticides, fertilisers, drainage, irrigation and levelling production sites affecting biodiversity (FAOSTAT country database, irrigation map of the world, WATERGAP). The impact of production management on biodiversity is formed by the sum of pressures based on technological choices or applications.

Nature management

A consistent strategy for nature conservation can be found in governmental regulations (at regional, national or international level) to control the exploitation of natural or cultural ecosystems. Examples of such regulations are the closed season or limitations on the total yearly extraction (in natural ecosystems) for fisherman and hunters. An example pertaining to agro-ecosystems in the Netherlands is the regulation of the period of application and the total amount of organic manure applied per hectare.

Civil society, especially production associations, has also defined regulations for nature management in production systems and have put limits on the application of technology (for both agro-ecosystems and natural ecosystems). Examples of production strategies are conventional, integrated management or organic farming (Stolton 2002). For example, in the fishing industry, a distinction should be made between technology (and the impact) of high-tech fishing on board and local fisherman with traditional technology. In general, production strategies differ in their impact on biodiversity. Such differences offer the opportunity of a positive impact on biodiversity when transition policies to more sustainable production systems are implemented. Impact on biodiversity can be assessed with the help of scenario analysis.

Disturbance

Agricultural production and exploitation of natural ecosystems are subject to unpredictable incidents or disturbances that are not related to management practices. These are external influences that may impact cultural landscapes, for example fire (MODIS, NOAA), diseases, pests, invasive species, natural hazards (earthobservatory.nasa.gov or WCMC) and human conflicts (UNEP-WCMC 2002). These factors alter socio-economic production conditions as well as the quantity and quality of the natural resources in and outside the production zone. The probability of the disturbance and the level of effects of such events are considered as a measure of the risk of ecosystem use destabilising with possible decreased production, accompanied by increased need for land and further land conversion or increased production. Both may result in biodiversity depletion.

Protection of natural ecosystems

Agroecosystems border on natural ecosystems. Protected areas may be situated in cultural landscapes or the landscape itself may be under protection. It is necessary to assess to what extent agricultural land may affect ecological protection goals in the cultural landscape itself (UNESCO, cultural heritage sites) or in nearby natural ecosystems (UNEP-WCMC or the IMAGE protected area map). A trade-off between production and protection is also possible. The protection measures may put limitations on agricultural production through territorial planning, e.g. the determination of buffer zones.

5. Expectations of the model

The framework described above shows how different factors could be included in the analysis. Starting point is an analysis of the extent, distribution and composition of cultural and natural elements in landscapes or land-use systems. The *first* hypothesis is that the more natural elements occur in cultural landscapes, the higher the chance of wild biodiversity and good connections between natural remnants sustaining even more biodiversity (including top predators and large herbivores or carnivores). Applying technology to production systems results in lower biodiversity. It is well known that the application of pesticides and fertilisers in the system or external pressures outside the system result in decreased abundance and distribution of plants, insects and, indirectly, animals in the trophic chain. The *second* hypothesis is that increased external capital investment would lower biodiversity. Additionally, nature management is likely to increase biodiversity if it improves environmental care or specific nature conservation. The same cause–effect relationships on production and biodiversity in the system, as well as pressures from agriculture on nearby natural ecosystems, will be calculated for factors from outside the system. In summary, all factors previously described relate to biodiversity based on dose–response relationships obtained from a literature review using ecotoxicological risk assessment (Posthuma et al. 2002). The factors are grouped according to their place in the model and the effects of these groups of factors are calculated by indices. The expectation is that wild plant and animal species biodiversity in agricultural landscapes will be generally low, depending on the intensity of the production system. However, important improvements may be obtained if production systems are moving in a transition phase to ecological sustainability, and if natural remnants in those areas are carefully managed or protected; they may even be enlarged.

The rule-based pressure approach of the Global Biodiversity Model for agricultural landscapes is a short-cut method in the species-based model. This model also includes natural terrestrial, aquatic and marine ecosystems and, more important, makes use of an additional species-based modelling procedure (RIVM 2002; Ten Brink et al. 2002). The expectation is that the pressure –impact relationships of the rule-based approach at system level may provide the required input for working at species level. A set of characteristic wild plant and animal species must be selected for all relevant agricultural livestock landscapes. Environmental factors determining species occurrence (abundance or distribution) are combined for each species. If environmental conditions change due to human action, the changed occurrence (distribution or abundance) of a species represents a measure of decreasing ecosystem quality, and thus a measure of decreasing biodiversity.

6. Communication and software requirements

The Global Biodiversity Model will be constructed by an international team. First, team members will have to communicate frequently on the concepts, data delivery, calculation procedures and presentation of outcome, and will therefore need Internet support (e.g. a protected web site for members only). In a second stage, data as well as published model results, can be distributed on the Internet for the public in general. A clear requirement of the software is communication enhancement and joint learning.

Past experiences and current IT developments at RIVM have led to the decision to use the ArcIMS web-mapping technology from ESRI to make the input data and projected results available on the Internet. Visitors (team members only) are offered simple online GIS functionality (like zoom, pan, select, buffer, add local data) to use on the global data and results, and will be able to download the data/results for further modelling. This technology is also used, for example, at WCMC for publishing I-maps like the World Atlas of Biodiversity.

The IT infrastructure will consist of an ArcIMS 4.01 Internet Map Server (on a Windows 2000 Advanced Server system) in combination with ArcSDE 8.3 (spatial data engine) and the Oracle 9.i database (both on UNIX). Local analyses, simple grid manipulations and overlays are carried out at RIVM with ArcINFO / ArcGIS 8.3.

What is currently missing in this framework of GIS software is a model builder with which users may combine a personal (local) set of relevant pressures or state variables and calculate their own pressure indices or biodiversity impact. This is especially relevant for future project members at national level, such as the current pilot counterpart ULRMC for Ukraine. They will need to combine assessment of global databases with assessment based on country data. It will be unlikely that the complete model framework software will be offered on Internet, because of copyright on each model and the complexity of working with the models. But Internet and ArcIMS software must be the right tools to communicate efficiently and effectively using quick scans carried out in the pressure approach as proposed in this paper.

7. Call for exchange of databases and joint analysis

The members of the Global Biodiversity Model are now faced with an intellectual and communicative challenge in building the model and producing biodiversity assessments for natural and agro-ecosystems with both rule-(quick scan) and species-based approaches.

The most powerful model will result by linking the information at national level with global-scale analysis and vice versa. Biodiversity assessments are generally carried out on specific spatial, temporal and organisational scales according to their appropriateness for the process or phenomenon being examined. However, focusing on one level will probably result in our missing one or more types of causes or ignoring interactions between scales that are "critically important in understanding ecosystem determinants and their implications for human well-being" (MA 2003; see p. 14). We therefore invite the scientific community to support this effort, to communicate improvements and to link relevant databases at global, regional and national levels.

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