

GIS-Based Model to Predict the Development of Biodiversity in Agrarian Habitats as a Planning Base for Different Land-Use Scenarios

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Abstract Biodiversity is defined in the political sphere as an important subject of protection and the extinction of species to be listed here should not only be held in acknowledged protected areas, but rather also in areas used agriculturally. The situation in agriculture is currently strongly changing through influencing factors, such as climate change and restructuring in favour of renewable resources. Since this development on the one hand holds the risk of a loss of biodiversity, and on the other redevelopments also offer opportunities, this is indispensable for a well-founded evaluation to operably forecast the effects of land use change on organisms. Suitable methods for this are currently lacking. These loopholes should be closed by the model worked out here. Based on species collections from earlier studies, autecological organism data from the bibliography, as well as suitable map material, a Geographical Information System will be created which makes it possible to forecast biodiversity in a regional context.

1 Historic Development and Current Situation of Biodiversity in the Agricultural Landscape

Except for a few, island-like confined locations, the landscape existing in central Europe today can by no means be described as “natural”, i.e. not influenced by people. Moreover, it has already been greatly changed through anthropogenic use in pre-industrial times. Without this influence, beech forests and mixed beech forests would above all dominate in Germany on the basis of the given climatic and

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edaphic conditions. Deforestation has however produced a mosaic of forest and non-forested land, over-use has led to a degradation of many regions, in which open brush-land and moorland have come into being. It is to be assumed that this increase in biotope diversity is also accompanied by a significant increase in biodiversity. This development was reversed however with industrialisation in the middle of the 19th century, which in agriculture led to mechanisation, growing farm sizes and an increase in fertilisation and use of pesticides; the biological diversity of the artificial landscape again decreased. This trend intensified in the middle of the 20th century through another drive of technology and innovation, strong growths in productivity accompanied further devastation of habitats and decreasing diversity in the agricultural landscape. It was not until the 1970s that increased efforts to protect nature and biotopes were made [6].

In spite of this, loss of biodiversity has also continued. The main cause of this is mentioned by Möckel [35] as being the change from an extensive, varied agriculture and forestry to the intensive farming of today, which levels out the landscape through land consolidation and melioration, extensive mono-cultures, ploughing up, intensive use of fertilisers, pesticides, high grazing density, drainage of wet locations, locations with marginal yields becoming fallow etc. Accordingly, the loss of biodiversity in agricultural lands is significantly larger than in areas close to nature [6, 21, 47, 49, 53].

In an international context and also in Germany, pressure on agricultural ecosystems is currently intensifying through changed framework conditions in agriculture. Alongside changes through direct and indirect effects of global climate change (Federal Office of Environmental Protection [7]), the growing competition through globalisation, high demand for and promotion of biomass from the energy sector, obligatory laying fallow of land ceasing to apply, increasing land competition and higher competitiveness of field use, increased intensification of field and grassland use, stronger utilisation of lands set aside, as well as ploughing grass lands for field use are to be mentioned in this regard [Cf. 35, 37]. The risk of loss of biodiversity through the extension of renewable resources, which are used as energy (production of heat/cold, power, fuel) and industrial plants (fibres, chemical and pharmaceutical products) in particular is referred to many times (e.g. [13, 16, 20, (Panel of Experts for Environmental Issues) 48]). It is therefore the declared goal of the Federal Government of Germany to increase the proportion of renewable energies in gross final energy consumption to 18 % by 2020, 30 % by 2030, 45 % by 2040 and 60 % by 2050 (German Federal Ministry for Economics and Technology and German Federal Ministry for the Environment, Environmental Protection and Reactor Safety [11]). Renewable energy sources should replace the only limited fossil and nuclear energy sources and therefore make a large contribution to conservation of resources and to controlling the greenhouse effect (Federal Environmental Agency [55]). Furthermore, the addition of bio-components to fuels should be increased [11]. For this purpose, large areas will be needed for the cultivation of renewable resources. If the proportion of agricultural areas used in such a way still amounted to 11.8 % in 2005 (German Federal Ministry for Nutrition, Agriculture and User Protection [8]), forecasts assume that the proportion of the areas available

for this will increase by more than 50 % by the year 2050 (Institute for Technical Thermodynamics (German Aerospace Centre) [26]).

This current and still to be expected process of restructuring the agricultural landscape does not only bring risks, but can also bring opportunities for biodiversity, since reform and land use change also always offer scope for design [53]. Agriculture is at a crossroads in this regard, and it now depends on which direction of development will be taken, and how far insights from research on the support of ecological objectives are integrated in systematic agricultural use (e.g. increase in structure variety).

At the same time biodiversity is defined as a subject of protection in a political framework. Protection and sustainable use of biodiversity are therefore objectives of the Convention on Biological Diversity, CBD, which was negotiated by the United Nations in Rio de Janeiro in 1992, and includes the European Union as one of its signatories. The term biodiversity here includes the levels of ecosystems, species and genes. The Convention enjoins the participating states to develop their own national biodiversity strategies [56]. This was done in Germany in 2007 with the National Strategy for Biodiversity (NBS). Here the goal was stated as stopping the extinction of species by 2010 and reversing the process, which applies to the entire landscape, including intensively used areas. Up to 2020 biodiversity in agricultural ecosystems should be significantly increased [9]. In 2010 the goal of maintaining biodiversity was however unsuccessful, and since the gap between the actual and intended values was still large, the goal for 2010 can only be reached under very great efforts [10]. Alongside the agreements mentioned, biodiversity as a subject of protection or conservation of a habitat function is also anchored in numerous other laws on national and international levels, such as the Cartagena Protocol [12], Directive 91/414/EEC (EU 1991, Pest Control), Directive 2001/18/EC (EU 2001, Use of GMOs), GenTG (German law on genetic engineering [22], Use of GMOs), BBodSchG (German federal law on soil protection [2], § 1, Soil Protection), PflSchG (German law on plant protection [41], § 6, Pest Control), Natura 2000 [50], BNatSchG (German law on nature protection [4], § 1 and § 5, Nature Protection), UVPG (German law on environmental impact assessment [58], Impact Regulation), USchadG (German law on environmental damages [57], Avoidance and Remediation of Environmental Damages).

Decisions on land use are however often made on the basis of short-term, mostly economic considerations, and higher sustainability concerns often remain disregarded.

2 State of Current Research

There are currently no suitable methods to operably forecast biodiversity in agricultural landscapes, and, according to the Commission for Soil Protection at the “Umweltbundesamt” (Federal Environmental Agency [29]), there is currently no knowledge about evaluating the landscape in the case of a change in the systems of use; it is therefore recommended to investigate the development of biodiversity when

there are conversions in the relevant model regions. Evaluation of risk for biodiversity outside of authorising materials is generally based on the protection, conservation and/or development goals of nature protection law rules. Corresponding protection targets are predominantly defined for all species or respectively habitat types to be protected, but not for all species and habitat types not considered worthy of protection. The landscape in Germany is not however made up entirely of nature reserves, but rather primarily from anthropogenically used areas (for agriculture, settlements and traffic) which are not under any strict nature protection [47, 54].

Models which deal with damages to species and changes in habitats mostly only focus on climate change. In order to assess sensitivities, dynamic approaches such as bioclimatic modelling e.g. [3, 38] or vulnerability analyses e.g. [25] are used. The dynamic models currently available in science are to date still restricted to global issues, which cannot be transferred to concrete local situations [27]. In the area of practical nature protection, primarily indicator-based sensitivity analyses are carried out, which in their structure correspond to the approach of a vulnerability analysis. So, for example, the risk assessment of possible changes to FFH areas in Germany as a result of climate change follows the methodology of indicator-based sensitivity analyses [40]. Similar studies have already been carried out for individual federal states, or are currently being carried out in North Rhine-Westphalia [31]. Within the framework of these studies, the plant species of individual habitats are grouped and defined in sensitivity levels according to the proportions of hygrophytes and plants growing in cold conditions:

<10 % cold or respectively humidity indicators 1 (low sensitivity), 10–20 % cold or respectively humidity indicators 2 (medium sensitivity) and >20 % cold or respectively humidity indicators 3 (high sensitivity). Climatic changes are not however the only influence on species or habitats. Other environmental changes related to humans such as the deposition of pollutants or changes in land use are significant factors involved which are not considered within the framework of the studies described above.

In addition, the studies are mostly limited to the analysis of legally protected types of habitat, for which there are clear requirements and conservation goals. The typical habitats, predominantly less worthy of protection, of an agricultural landscape are not considered in such studies. A conceptual approach to the evaluation of biodiversity in the agricultural landscape is lacking.

Moreover, no positive development can be represented through the approaches currently available, but rather only the risk of negative consequences is forecast.

Within the framework of the national strategy for biodiversity, 19 indicators were developed which in their monitoring also cover endangered species (red list) as well as protected species within the FFH areas alongside sustainability indicators. Moreover, the states of preservation of areas with special protection status form the focus of the monitoring. As an indicator for recording sustainability, a total of 59 types of bird from six different types of habitat were brought in Achtziger et al. [1], which were determined in the course of the national sustainability strategy. For the part habitat of agricultural land, ten types of bird are representative for biodiversity in this habitat. The fact that only such a small number of species are

incorporated into the indicator is due to the fact that the information should be evaluated with an overview. This inevitably produces an area of tension between scientific exactitude and political usability [59]. The principle of representative species is used also in the area of risk analysis of pesticides [46]. It poses the question, however, as to whether this concept is sufficient for a well-founded evaluation.

Collecting monitoring data, above all of animals, is very complex and cost-intensive. There are therefore only few such data, and those which are collected often remain unused, since they are not centrally held and evaluated. An operationalization of biodiversity is therefore required urgently in order to make the data comparable [28]. The ecological area referred to must in doing so always be observed however, i.e. the local, regional natural states and potentials have to be sufficiently taken into consideration. If this does not happen and general nature protection areas are transferred to all locations unconsidered, overall this does not amount to promoting, but rather to levelling out natural diversity [42].

3 The Principle of the Model to Forecast the Development of Biodiversity in Agricultural Habitats

A model such as that created within the framework of this work represents biodiversity in a spatial relationship and makes it possible to operationalise. It is therefore possible to integrate and therefore make usable monitoring data already collected in management concepts for land use.

On the basis of regional prevalence data on plants and animals, biodiversity should be forecast in various agricultural habitats. If a land use change is taken into consideration for a particular area, this allows the model to assess the effects of this change on the composition of the local agricultural biocenoses. The model should initially be developed using the two organism groups of vascular plants and ground beetles (as representatives of ground-proximate arthropods). The model systematic can later be extended to other groups such as birds, spiders, butterflies or grasshoppers. It will initially be developed on the example of the Rhineland. It can however be transferred to other regions later.

4 Selected Organism Groups

Animal and plant organisms are adapted to different degrees to biotic and abiotic location factors, such as temperature, rainfall, the type, quality and wetness of soil, as well as food supply, and form a characteristic community of a habitat through inter- and intraspecific interdependencies, such as, inter alia, competitive behaviour, symbioses or predator-prey relationships [30]. Both the different animal groups and also the vegetation therefore also give indications of the environmental influences at

the location through the species composition of their biocenoses and thereby serve as biological indicators for these ecological conditions [15, 30]. Requirements for the suitability of particular animal groups, as well as vegetation as indicator organisms are a broad ecological distribution, a characteristic reaction of the biocenoses to the different biotic and abiotic parameters, as well as comprehensive knowledge about the autecology and the incidence of species [32, 44].

A frequently studied animal group is the ground beetle family (coleoptera, carabidae). It is distributed globally, the autecology of native species is widely known and the influences of different local factors on the carabidae community has been described many times [19, 33, 36, 51]. In particular there is comprehensive knowledge about the incidence, the living and adaptation strategies of the carabidae in agricultural landscapes [23, 24, 34, 52]. Carabidae are therefore well suited for answering ecological questions [44].

Plants also form characteristic biocenoses under the influence of local conditions. If these species communities can be reproduced under defined environmental conditions, they are described as plant communities [43]. The incidence of individual plant communities is also marked by local influences so that particular indicator properties can be attached to the incidence of these species in a habitat [17]. As a result both the plant community encountered in a biotope and the evidence of characteristic indicator species indicate the environmental parameters in a defined habitat [5, 14]. On the basis of its ecological demands, vascular plants at a particular location again possess indicator properties for particular preferred environmental conditions. In order to be able to quantify these properties, the plant communities have been organised according to their location demands for a special local parameter (e.g. shade or pH value) with an integer value (Ellenberg number) between 1 and 9 [15, 17]. Although the Ellenberg numbers are scaled ordinally, it is common in practice to form the arithmetic mean from the Ellenberg numbers of the plants of a defined location in order to be able to derive statements about the environmental conditions at the location [18]. Ellenberg numbers which are important for the model are the temperature number and the moisture number, which are influenced by the climatic conditions. The nitrogen number is also relevant, which allows for statements to be made about the intensity of land use. A high moisture number means that a plant species predominantly prefers moist soils, a high temperature number indicates a preference for higher temperatures and high nitrogen numbers indicate fertiliser indicators [15, 17].

5 Development of the Model

The model is made up of organism databases on plants and ground beetles on the one hand, and cartographical material on different subjects (types of biotope, soil parameters, climate data) on the other. These are brought together in a Geographical Information System (GIS), from which also the forecasts about the expected species are ultimately made.

In order to create the organism database, for one part real distribution data of plant and ground beetle species shall be used, which has already been collected in earlier work in the Aachen area [45]. These data are particularly suitable since, with 93 vegetation records and almost 50,000 carabidae individuals from 85 species, they are very comprehensive. Besides that they were collected at 37 locations in several different types of biotope (forest, hedge, meadow, as well as park-like areas), which are also partly relevant for the agricultural landscape. Since when collecting data for all recordings the exact coordinates of the place where things were found were recorded, it is now possible to combine the species found with the factors present at the place they were found (type of biotope, soil parameter, climate data). In the database produced from this, the preferences of each species regarding their abiotic and biotic surroundings are included. Should it emerge that, based on the Roß-Nickoll data collected, no sufficiently precise model can yet be created to forecast the incidence of organisms subject to the environmental factors mentioned, there are further species collections for different projects and bachelors theses which can be integrated into the model and contribute to its refinement and sharpening of the prognosis. Furthermore, autecological data on the preference of the named environmental parameters in the individual taxa are compiled from the literature.

The cartographical material on the subjects of the types of biotope, soil parameters and climate data are blended with a Geographical Information System. In this way all spatial units can be assigned property combinations, that is to say, that for each point of the area worked on it is known which type of biotope there is and how the soil and climate are constituted.

The organism databases are likewise read into the Geographical Information System. For the connection between organism data and environmental factors it is indispensable that the particular categories match. Now a first sample forecast on the species composition for selected locations can be made to verify the model. For each species, one obtains a probability of its incidence. It is checked by experiment whether the forecast species are also actually to be encountered in the areas. If this is not the case to a sufficiently precise extent, the model must be further optimised by either integrating even more distribution data of the organisms already collected within the framework of other projects, or by parameterising the autecological data in such a way that they fit the distribution data. This is an iterative process, i.e. settings are changed step by step until one reaches realistic results. For this verification and optimisation stage, data should be used which has been collected in 2011 within the framework of a university thesis [39]. The areas of study are located in two different broad expanse areas, one in the Lower Rhine Bay (Jülicher Börde) at Niederzier-Selhausen (Düren administrative district, ordnance survey map 5104 Düren), the other in Nordeifel at Simmerath-Rollesbroich (Aachen administrative district, ordnance survey map 5303 Roetgen). In each of the study areas the biotope types grassland, field and hedge were tested. Beside 30 vegetation records, more than 5,500 carabidae individuals from 54 species were recorded. It could be shown in the work that there are very specific regional patterns in the distribution of ground beetles, which on the one hand depend heavily on use, and on the other hand probably also react sensitively to expected climate changes.

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Fuels From Biomass: An Interdisciplinary Approach

A collection of papers presented at the Winter School

2011 of the North Rhine Westphalia Research School

"Fuel production based on renewable resources"

associated with the Cluster of Excellence "Tailor-Made

Fuels from Biomass", Aachen, Germany, 2011

Klaas, M.; Pischinger, S.; Schröder, W. (Eds.)

2015, VIII, 311 p. 204 illus., 33 illus. in color., Hardcover

ISBN: 978-3-662-45424-4