GIS-based modeling of land use systems: EU Common Agricultural Policy reform and its impact on agricultural land use and plant species richness

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Abstract

The paper presents the land use model ProLand and the fuzzy expert system UPAL. ProLand models the regional distribution of agricultural land use systems. UPAL predicts plant species richness. Linking land use and ecological models allows to assess socio-economic and ecological effects of policy measures by identifying interactions and estimating potential trade-offs. The effects of the Common Agricultural Policy Reform on land use, economic and social key indicators, and plant species richness are modeled for a study area in Hesse, Germany. Results indicate that the Reform positively influences land rent and species richness.

Keywords: land use modeling, fuzzy expert system, species richness

1. Introduction

1.1. Problem statement

Land use is a function of natural, political, socio-economic, and technological variables. Changes in landscapes arise from technological innovations, as well as from socio-economic and political developments (Rounsevell et al, 2003; Stoate et al. 2001). These changes impact a landscape's appearance, and may cause both positive and negative effects on soil, water and air quality, flora and fauna habitats, and citizens' health (Hansen et al., 2001; Stoate et al., 2001). The concept of multifunctionality emphasizes the fact that landscapes have multiple outputs and contribute to several of society's objectives at once (European Commission, 1999; OECD, 2001). Thus, assessments of agricultural policy measures and their sustainability need to consider economic, social, and ecological aspects.

The current paradigm shift of the European Union's Common Agricultural Policy (CAP) from coupled to decoupled transfer payments is a drastic change of the political forces influencing

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agricultural land use (cp. European Commission, 2004). Land users have to reevaluate their production program and its spatial allocation as payments are no longer coupled to certain crop or animal species. Thus, the CAP Reform sets incentives for farmers to allocate resources according to market demand and prevailing natural conditions. Consequently, agricultural policy affects regional land use patterns and shares of land use systems, which in turn influence plant species richness.

Planners and policy makers involved in these processes need significant information showing the consequences of different courses of action (Antrop, 2004). Spatially explicit decision support systems are helpful tools in evaluating landscapes with respect to economic benefits, as well as ecological objectives. A spatially explicit land use model is essential for such multifunctional landscape evaluations (Bockstael, 1996) as environmental changes frequently trace back to land use changes (Lambin et al., 2000).

Conventionally, land use models concentrate on economic components. As elaborated above developments concerning e.g. biodiversity should be evaluated as well. Two approaches may provide such results. First, connecting a land use model with biodiversity models, and second, extending the land use model with biodiversity components. Independent from the selected option, the spatial component of land use is of outstanding relevance. “It is not just the total forested land in a region that matters for species abundance and diversity, but its size, shape and the conflicting land uses found along its edges.” (Bockstael, 1996).

Accordingly, land use models should provide spatially explicit prognoses. Many models exist already generating predictions on the spatial allocation of land use systems, and on socio-economic indicators like added value or rate of employment (cp. Münier et al., 2004). The main focus lies on economic aspects however. The spatial component in these models is of minor interest. This sets them apart from ecological models, which stress explicit spatial information (Bockstael, 1996).

The models presented here are both spatially explicit and connected through a GIS. ProLand models the regional distribution of agricultural land use systems while UPAL predicts plant species richness. This allows to assess socioeconomic and ecological effects of policy measures by identifying interactions and estimating potential trade-offs.

1.2. Scenario descriptions

The German national implementation of the CAP reform came into effect at the beginning of 2005. The former policy “Agenda 2000” is gradually phased out during a transition period until 2013. Key elements are the decoupling of transfer payments from the production program, requirements regarding “Cross Compliance” and the redirection of funds from the first to the second pillar (“Modulation”) (BMVEL, 2005). The decoupling of direct payments from the production program is an important modification affecting the evaluation of land use systems based on land rent.

During the Agenda 2000 period farmers received direct area payments for certain crops and animal premiums for certain cattle production systems. Farmers were forced to produce to receive payments. Animal premiums were a function of the number of animals produced and area payments a function of how many hectares of land were tilled with specific crops.

Decoupling in the sense of the CAP reform means that all farm land units previously used for production will receive identical area transfer payments. These payments are independent from what or how much is produced. Farmers only have to comply with certain requirements and keep the land in “good agricultural and ecological condition” (BMVEL, 2005). Decoupled payments no longer influence a land user’s decision for a certain production system and the intensity of land use.

Land use systems which previously could have yielded the maximum land rent on a spatial unit only because of coupled animal and area payments have to be reassessed. Two scenarios were created to model the effects of political, technological, and socio-economic conditions before (Agenda 2000) and after (CAP) the CAP reform.

With the new CAP land users may choose among five options: (1) Maintain the existing land use program. (2) Maintain the existing land use program, but change its intensity. (3) Switch to a different land use system. (4) Cease agricultural production but keep fields in “good agricultural and ecological condition” in accordance with the Cross Compliance requirements. (5) Abandon the fields to natural succession and waive the area payments.

The model calculations are applied to a less favored region, the Lahn-Dill-Highlands in Hesse, Germany. The region of about 1,100 km² is characterized by unfavorable natural conditions in terms of water availability and temperature, and small agrarian structure. The share of forest is about 55 %, most remaining land is used as grassland.

General political and economic conditions for both scenarios reflect those in the state of Hesse. The most important legislative constraint concerns forests which must not be converted to other land uses. Transfer payments from the second pillar that are not affected by the reform, such as payments from conservation programs, are not altered. Quantity and input price structures of the land use systems reflect the situation in 2004. Output price structures were adapted to the respective years.

In the Agenda 2000 scenario output prices were calculated from time series data provided by the German agricultural market and price recording agency (ZMP, 2002a-2004a; ZMP, 2002b-2004b). Transfer payments are coupled to certain land use systems and vary between systems. Grassland receives no crop premiums if tilled and converted to arable land, which is a major difference to the CAP scenario. The CAP scenario was defined with transfer payments set to the values projected for 2013 as ProLand models endpoints of adaptation processes. Prices were adjusted accordingly, based on projections by the model AGRISIM II (Borresch et al., 2005), also part of the ITEEM model framework developed at the SFB. Contrary to the first scenario, converted grassland receives area payments.

Assumptions concerning production technology have a decisive influence on the economic evaluation of land use systems. Different technology requires varying factor amounts and different factor combinations. For each crop two standardized mechanizations typical for the region are assumed for all field operations. They conform mostly with data published by the Association for Technology and Structures in Agriculture (KTBL, 2002). Self-produced fodder is valued by taking the value of the animal products produced with it less their production costs. The factor requirements of animal husbandry are simulated based on KTBL data from 2003/04 (KTBL, 2003). Using the yearly fodder requirement and the potential yield allows to transfer the factor consumption in animal husbandry to the spatial units. Factor prices for labor and capital are identical in both scenarios but are generally variable between scenarios. The wage rate was set to 11 € per hour, the interest rate at 3.5 %.

2. Model descriptions

The models ProLand (Weinmann, 2002; Kuhlmann et al., 2002) and UPAL were developed at the collaborative research center SFB 299 "Land Use Options For Peripheral Regions" at the Justus Liebig University, Giessen. At the center researchers from multiple disciplines investigate land use options for less favored regions. Research is funded by the DFG, the German Research Association. Objective is the development of transferable models and strategies that can support politicians and other stake holders in their decision process.

2.1. The land use model ProLand

2.1.1. Basic assumptions and modeling approach

ProLand is a spatially explicit, deterministic, comparative static model that simulates a region's agricultural and forestal land use pattern. The model's basic rationale is that land use patterns are a function of site specific natural, socioeconomic, political, and technological parameters. The model predicts the spatial allocation of agricultural and forestal land use systems based on small-scale information on the spatial distribution of physical, biological and socio-economic characteristics of a region. Its results have to be interpreted as endpoints of adaptation processes. Costs of adaptation, however, are not considered yet.

Land use systems are characterized through crop rotation, corresponding field operations, animal husbandry if applicable, and relevant political and socio-economic attributes. They are categorized into arable farming, grassland, forestry, and fallow. Developments, roads and miscellaneous land uses are external constants and are not modeled. Pork, egg and poultry production are assumed to be spatially independent and therefore without effect on regional land use patterns.

The model assumes land rent maximizing behavior of land users. The concept of land rent is an appropriate and useful approach to measure the potential economic performance of land (cp. van Kooten, 1993, p. 15 et sqq.). However, farmers employ a certain combination of the production factors labor and capital to maximize land rent. The factors labor and capital achieve a certain level, measured as realistic opportunity costs.

Accordingly, land rent is calculated as (cp. Kuhlmann et al., 2002):

(1) $$R = \frac{P - LC - IC - MC}{A}$$

where

R = land rent

P = profit

LC = labor costs

IC = interest

MC = material costs

A = total land area farmed by land user

The model calculates and assigns the land rent maximizing land use system for every individual decision unit in a region. These decision units are polygons of arbitrary size and shape.

Information on bio-productivity and local production costs are needed to calculate the land rent for different land use systems at different sites. Potential yield, field size, and slope affect production costs and thus the economic benefit of land use. Spatially explicit information on size, shape and biotic productivity of every decision unit is especially important in regions with heterogeneous parcels. Minimal changes strongly affect the relative preference of land use systems (Möller et al., 1999). Consequently, assuming an average field size for large regions may lead to false results. ProLand derives decision units from polygons bound by roads and field paths as provided by ATKIS data (ADV, 2004). Generally, these units can be assumed to be identical to the actual field. While this approach still has considerable error it captures the regional distribution of field sizes better than an average figure for an entire region. Obviously, these decision units frequently have heterogeneous site parameters, e.g. soil composition, slope etc.. By assigning sub-polygons with such site specific information derived from 25 m x 25 m raster elements to the actual decision units ProLand retains high resolution information while modeling larger polygons. The model estimates the land rent for each of these sub-polygons and each land use system and selects the land rent maximizing alternative. As sub-polygons can be of different size it then calculates the area weighted average of the land rent for the entire decision unit. Finally, the land rent maximizing land use system is assigned to each ATKIS polygon.

Land rent on a decision unit results from the weighted average of the difference of costs and benefits on each sub-polygon. Equation 2 is a simplified version of the objective function, as it only differentiates between arable farming, grassland and forest. The actual model results are more detailed.

$$\begin{aligned} LR_{max,k} &= Max\left[LR^{arable}_{max,k}, LR^{grassland}_{max,k}, LR^{forest}_{max,k}\right] \\ &= Max\left[\sum_{a=1}^{w}\left(\sum_{i=1}^{n} A_i\left(B_{a,i} - C_{a,i}\right)\right), \sum_{i=1}^{n} A_i\left(B_{g,i} - C_{g,i}\right), \sum_{i=1}^{n} A_i\left(B_{f,i} - C_{f,i}\right)\right] \end{aligned} \quad (2)$$

with:

$LR_{max,k}$ = maximum achievable land rent on subpolygon k [€/ha],

$LR^{arable}_{max,k}$ = maximum average land-rent of crop rotation on subpolygon k [€/ha],

$LR^{grassland}_{max,k}$ = maximum land-rent of grassland on subpolygon k [€/ha],

$LR^{forest}_{max,k}$ = maximum land-rent of forest on subpolygon k [€/ha],

A_i = share of subpolygon i (i=1,..,n) in total area of polygon k ,

$B_{a,i}$ = benefit of production system a (a=1,...w) in crop rotation selected on subpolygon i [€/ha],

$C_{a,i}$ = production costs of production process a (a=1,...w) in crop rotation selected on subpolygon i [€/ha],

$B_{g,i}$ = benefit of grassland production system on subpolygon i [€/ha],

$C_{g,i}$ = production costs of grassland production process g on subpolygon i [€/ha],

$B_{f,i}$ = benefit of forestal production process on subpolygon i [€/ha],

$C_{f,i}$ = production costs of forestal production process f on subpolygon i [€/ha].

Basis for the calculation of the economic benefit B of a land use system on a sub-polygon is a yield estimation according to a Liebig function (Weinmann, 2002). The potential yield of a crop is a function of the uncontrollable production factors temperature, water, and genetic potential. Land users are assumed to employ controllable production factors such that they do not limit crop yield. Factor consumption quantities are derived from yield potential, i.e. crop yield is a model endogenous variable, not an exogenous parameter. Yield is multiplied with market price respectively the value added by animal production for unmarketable crops. Transfer payments for both animal and crop production are added to obtain the financial result of each land use system.

The model predicts land use for different scenarios, i.e. changing exogenous parameter combinations. Factors include wage and interest rates, transfer payments, prices but also available land use systems consisting of crop rotation, animal husbandry and field operations. This allows to estimate trade-off functions from the generated output. Consequently, ProLand can be employed as an economic land use laboratory. Such scenarios illustrating various development paths provide useful information for decision makers.

2.1.2. Database concept

The necessary information to evaluate equation (2), production process specific figures, and correction factors, are stored in a dedicated database. The database was developed using an entity-relationship model for agricultural and forestal land use systems and implemented with a relational database management system.

Land is used through land use systems, which are groups of independent but interrelated elements comprising a unified whole. Applying the entity-relationship data model, a land use system at the primary level consists of the entity sets crops, field operations, and animal husbandry and their relations. These entities are described using biological and technological attributes, specific to each entity. These systems are determined by political, socioeconomic, natural and technological conditions and their relations. A land use system at the secondary level is thus extended by these entity sets and the relations between all these sets. The model and database capture information on the entity sets, members, value sets, and attributes, and their relations while accounting for constraints set by the conditions listed above.

Consider the example of dairy cow keeping to illustrate this approach. To describe the corresponding land use system one needs information what fodder crops are grown (entity set crops), how these crops are produced (entity set field operations), and how the animals are kept (entity set animal husbandry). However, to comprehensively describe the system, additional information is required, e.g. transfer payments, interest rates, wage rates, production quotas etc..

The land use systems database reflects the biological, socioeconomic and political attributes of agricultural production. However, spatially explicit land use modeling requires additional site specific information on natural, structural and political attributes that influence the costs and benefits of land use systems.

Using a geodatabase to store site specific data on natural and political conditions, and landscape structure with the required attributes satisfies these requirements. Attributes include plant available water and temperature as non-controllable growth factors, site specific transfer payments, slope, and field size. The spatial resolution varies with the type of information stored. While the polygons containing information on natural conditions were derived from a 25 m by 25 m raster, fields are stored as polygons with their actual shape and size. Associating the higher resolution raster information with the field polygons allows to retain high accuracy while capturing the actual landscape structure. During the simulation process, each associated sub-polygon is estimated, one land use system is selected for the entire field polygon.

The generated results are stored in relational databases which are then associated with the corresponding spatial units in the geodatabase. This structure allows to perform further analysis. In addition to the land use distribution of a specific scenario economic performance figures are generated, stored, and can be visualized as maps, tables or charts. Also, results can be passed on to e.g. ecological or hydrological models.

The above described approach has several advantages compared to flat file or single table databases: It allows to store information without data redundancy, provides a means to integrate virtually all land use systems including energy farming, and conservation measures, and makes it possible to generate scenarios regarding markets, policy instruments and technological progress. Combining data on land use systems, e.g. transfer payments, with spatial data produces information that is essential for viable land use modeling.

2.2. UPAL – a fuzzy expert system for species richness

The model UPAL was build to assess the impact of the land use changes forecasted by the model ProLand on the species richness of vascular plants. The fuzzy expert system derives the values of ecologically relevant parameters from several site specific attributes and land use operations.

Land use dependent site characteristics that influence plant species richness are derived from predictions generated by ProLand. Detailed information on crop rotation, fertilization and pesticide strategy, and field operations are considered. The expert system then classifies natural and land use dependent site characteristics into aggregate factors. Based on a set of rules it assigns the number of species to these classes and thus to the decision units.

2.2.1. Requirements of UPAL

This approach entails some important requirements for the model UPAL. The model has to process detailed information on land use strategies. ProLand forecasts the land uses arable farming, grassland, or forest but also detailed strategies including crop rotation and life stock management. Thus, UPAL has to differentiate between a large number of land use systems. However, little or even no site specific detailed empirical data on the current land use systems are obtainable. Only information concerning the land use type, i.e. arable farming, grassland, or forest, are available. Evidently, it is virtually impossible to collect data on both land use system and natural attributes of a site. Thus, UPAL has to be able to assess species richness even if no specific data exists for a combination of land use system and natural parameters.

Also, the uncertainty of the assessment has to be calculated. Ecological systems are extremely complex. A large number of input parameters that can not be included in the modeling approach will always remain. Obviously, this results in an uncertainty concerning the number of occurring species. This uncertainty has to be documented with the output and passed on to other models.

Additionally, the output should be understandable by non-ecologists. It has to include an explanation of what a low, medium, or high number of species means in a specific context.

An approach complying with all these requirements is a fuzzy expert system. A model based on rules predicting how land uses impact species richness in a given region even if no explicit data is available is capable of processing detailed land use information.

2.2.2. Methods used in UPAL

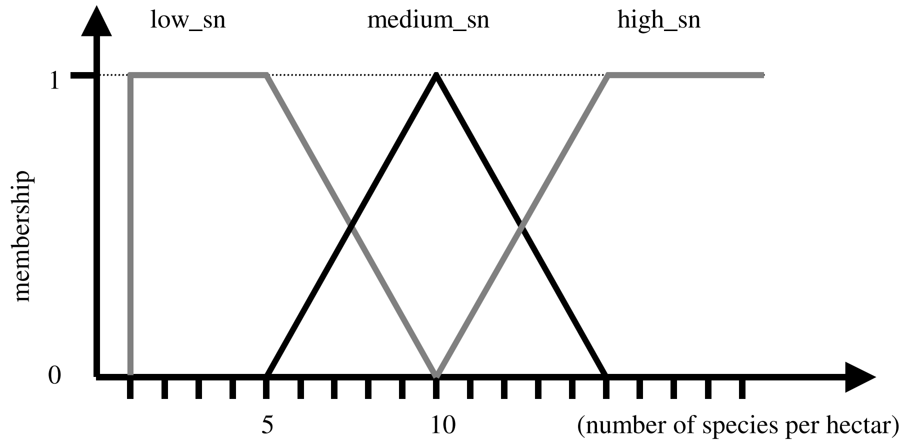
Over years of research many experts gained knowledge on the effects of land use strategies on plant species richness. A method to formalize this knowledge is a fuzzy expert system. These systems consist of a fuzzy classification, an inference based on rules consisting of an if-statement and a then-statement as the premise and the conclusion of the rule and the defuzzification transforming the fuzzy-sets to metric data.

The class definitions as well as the rule should have a fuzzy character to reflect the expert's uncertainty. This uncertainty seems to be threefold (Molenaar and Jansen, 1991). Uncertainty appears with respect to the definition of classes (or sets): What is the boundary between high and medium available water capacity? Secondly, the inference formalized in production rules can be ambiguous: How sure is the relation between premise and conclusion (Droesen, 1996)? Finally, when we apply these rules to a specific terrain element, a third source of uncertainty is the accuracy of the metric data taken from digital maps.

Classifying variables usually implies setting boundaries where one parameter state ends and the next begins. Obviously, attributes such as "low" or "high" do not define discrete start and end points. Instead, a set of numbers could refer to one attribute as well as to the other. Fuzzy sets allow classifying parameters without putting exact boundaries by allocating values to both classes with a certain membership value. The intension of a class is defined by a membership function on an attribute axis (cp. Illustration 1). For instance, the variable SN "species number on crop fields" is represented by three ordinal classes low_sn, medium_sn and high_sn. Note that variables are indicated by capitals, while classes are described in lower case. The intension of the classes is defined by a membership function on the attribute "number of species" indicated by x. For instance, the membership function of low_sn is denoted $SN^{low\_sn}(x)$. The value of variable SN for a specific site(i) is represented by three membership grades, one for each fuzzy class:

$$SN_{(i)} = (SN^{low\_sn}(x_i), SN^{medium\_sn}(x_i), SN^{high\_sn}(x_i))$$

Illustration 1: Membership functions of the classes of the fuzzy variable species richness of vascular plants on arable fields



Variables defined this way are called fuzzy variables (Klir and Folger, 1988).

The fuzziness of a class is governed by the range of overlap between classes. The overlap can vary for classes of one fuzzy variable. In the example the seperation of the classes l_sn and m_sn and the seperation of m_sn and h_sn is equal.

Fuzzy variables allow the transformation from metric data to verbal expressions. Fuzzy variables whose classes can be used as verbal expressions are called linguistic variables. These linguistic variables allow the verbal creation of rules and induce an output expressed by a linguistic variable. In this approach the output "number of vascular plant species" is expressed with the three main states "high", "medium" and "low". This way the output is self-explanatory to non-ecologists which simplifies the dataflow to other models.

The rules applied to the rule base consist of a premise and a conclusion. They can be described as simple "if-then"-terms. One or more input parameters allocate an output parameter. The rules represent the presence and the absence of association between classes. When presence of association is indicated with 1 and absence with 0, this is called a crisp relation. In general practice an expert is not equally certain of all rules. By indicating the strength of association by a membership grade, a fuzzy relation is obtained.

Table 1: Example for linguistic inference including uncertain assignments

Input parameter a	Input parameter b	Output parameter c	Membership grade of rule
"low"	"low"	"low"	100 %
"low"	"medium"	"low"	80 %
"low"	"medium"	"medium"	20 %
"low"	"high"	…	…

For every combination of conditional classes, a hypothetical dependent class is indicated.

Both the classification of fuzzy sets to fuzzificate parameters, and the rule creation are the subjective opinion of experts. They are expressed through membership grades. The membership depends on how certain a rule is. The possibility of integrating doubts, while having a good idea of what the rule should be, makes rule generation easier for the expert while improving the rule itself.

Defuzzification means translation of fuzzy sets to discrete metric data. Defuzzification is very important in fuzzy control systems when machines need to operate with the output of a fuzzy expert system. Because the first applications of fuzzy expert systems were created for fuzzy control there are many kinds of defuzzification methods.

The output of UPAL displays the change of plant species richness with fuzzy sets. Uncertainty of the system is part of the output. The fuzzy sets must be transformed to create outputs with discrete metric values.

One way is using linguistic variables to communicate changes in species richness. However, the outputs have to be defuzzificated to be displayed in digital maps. All defuzzification methods entail information loss. A connection between classes and metric data has to be created to defuzzificate linguistic variables. Every class needs to be connected to a fuzzy number. Here, the output is the linguistic variable species richness. The problem of creating fuzzy numbers based on classes for species richness is that these classes are relative. The meaning of low species richness depends on many factors. The most important factor is the climatic zone. The number of species in tropical rainforests is much higher than the number of species in central European forests. Another important factor is land use. The meaning of the species richness classes is completely different for fallow, forest, grassland and arable land. While eight species on an arable field could be classified as a medium number of species, the same number on fallow or grassland would be classified low. Fuzzy numbers for the classes of the linguistic variable species richness of vascular plants must at least differentiate between these generic land uses. Another important factor is the size of the area the variable refers to. The number of species increases with increasing size of the area it refers to.

Creating fuzzy numbers again requires the knowledge of experts. Defining the linguistic variables for species richness of vascular plants for generic terms of land use allows to defuzzificate UPAL's output parameters. The classification rules for the fuzzy variable species richness provide a tool to transform discrete metric values to linguistic variables.

2.2.3. Design of UPAL

Every plant species has a certain ecological optimum. If natural parameters fit this optimum the species can compete against others much better than under suboptimal conditions. This optimum is defined by several ecological parameters derived from natural parameters. The most important parameters are moisture, nutrient availability, soil acidity, temperature, and light impact. Furthermore soil salinity, soil heavy metal content, and the climatic zone are important. Some of these parameters are directly influenced by land use such as nutrient availability altered by fertilization and soil acidity altered by lime application. In agricultural areas only few ecological parameters depend on natural conditions: Temperature, mainly influenced by altitude and solar insolation, light impact, influenced by solar insolation and the current vegetation on a site, and moisture. A model considering natural parameters must include ecological parameters especially those not influenced by land use.

At present the model UPAL includes the parameters moisture, temperature and light impact in its calculations. Some parameters are disregarded like soil salinity and soil heavy metal content. The parameter climatic zone is considered constant in the research region. Others are derived only from land use based on ProLand's specification that all farmers employ optimal farming practices. Because of this specification ULAP assumes the parameters nutrient availability and soil acidity to depend on land use. This assumption does not apply to fallow. To integrate this land use the neglected parameters have to be integrated in the ecological parameter assessment as well. Currently, integration of fallow is unnecessary as ProLand did not forecast any permanent fallow in either scenario.

The impact of land use on species richness is very complex. Different land uses influence the natural parameters and change the ecological environment for plant species in agricultural areas. Furthermore land use influences plant species occurrence with physical stress factors such as grazing and mowing on grassland or application of herbicides on crop fields. All influences of the forecasted land use have to be considered and their impacts have to be integrated in the rule base. While some impacts on plant species richness are obvious such as an extremely negative influence of herbicide application other impacts are more difficult to assess.

The model UPAL consists of two modules. The first module assigns natural parameters to ecological parameters. The second module assesses what impact ecological parameters and land use have on species richness of vascular plants. Some parameters are fuzzy because they cannot be derived from all influential factors and because a site can have more than one state at the same time. These parameters have to be fuzzificated before they enter the inference. Land use is considered certain. It is the output of a comparative, static, deterministic model meaning that one land use per site is predicted. If ProLand predicted more than one land use per site this parameter would have to be fuzzificated as well.

Illustration 2: UPAL model structure

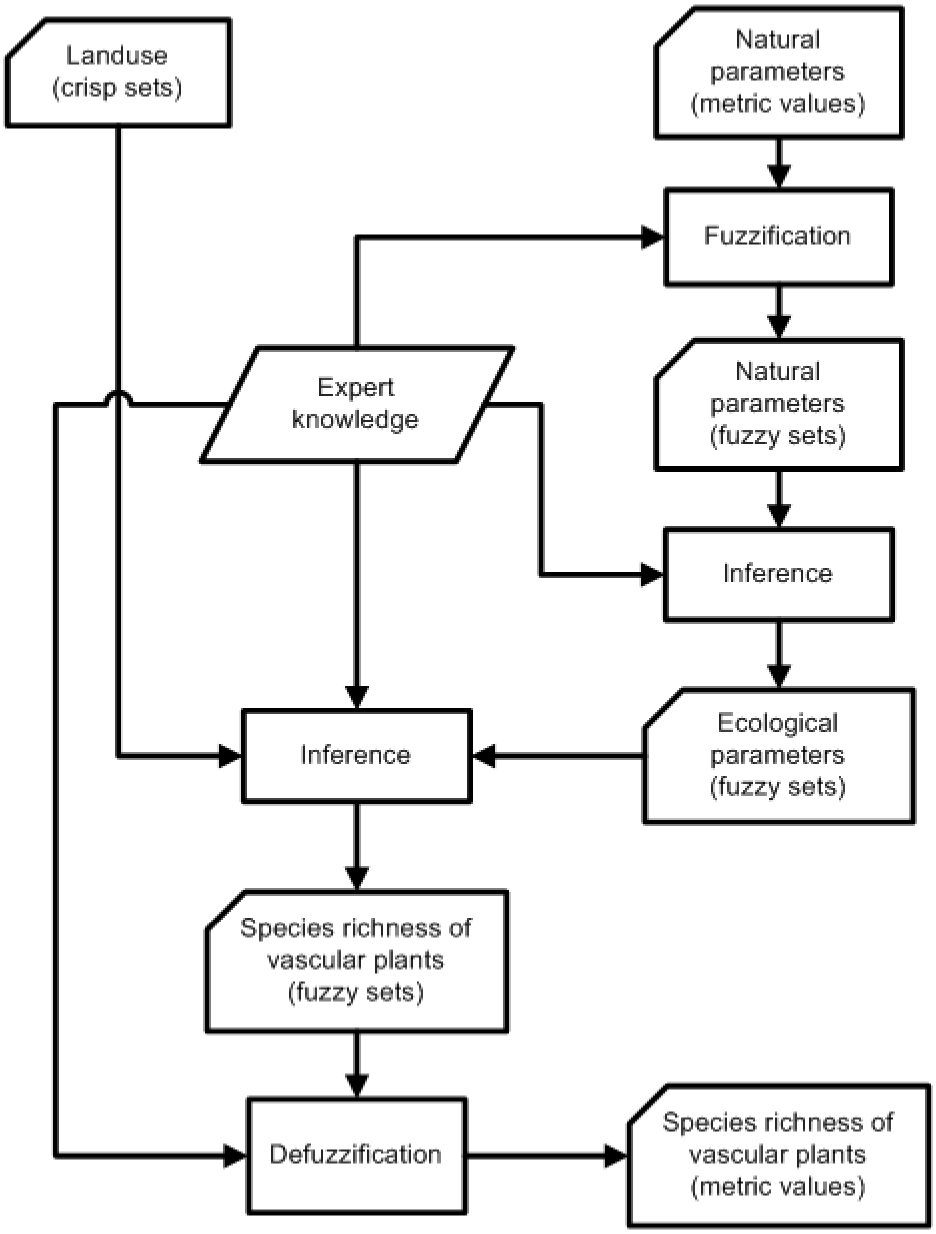
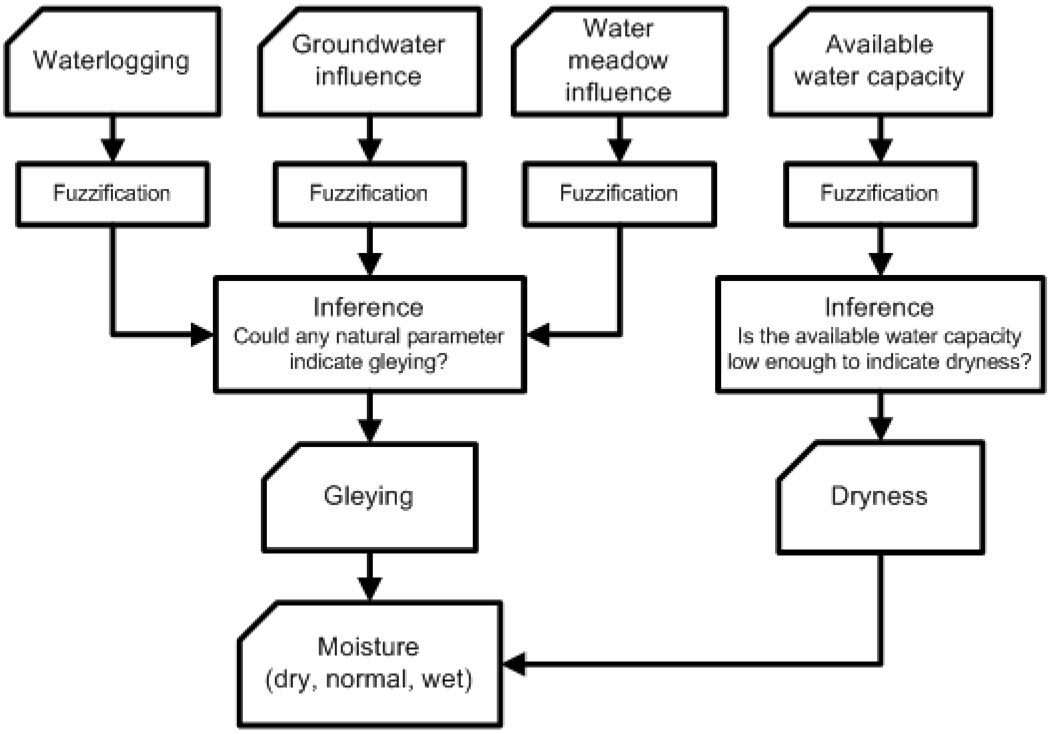


Illustration 3 shows an example for deriving ecological parameters. The parameter moisture is derived from the natural parameters available water capacity, waterlogging, water meadow, and groundwater influence. Three classes are derived for moisture from the parameters dry, normal and wet. A site is described by one class or a combination of two or all classes. The memberships always add up to 100 %. The linguistic variable moisture indicates clearly which sites are certainly classified and which are uncertain. The uncertainty on these sites will persist even in the second module.

Illustration 3 Deriving moisture from natural parameters



The second module derives plant species richness from land use and ecological parameters. It consists of several inference steps assessing the parameters' impact on plant species richness and combines these assessments with fuzzy operators. The impacts of the ecological parameters are combined with a union operator. The resulting fuzzy variable is combined with the plant species richness derived from land use by a minimum operator.

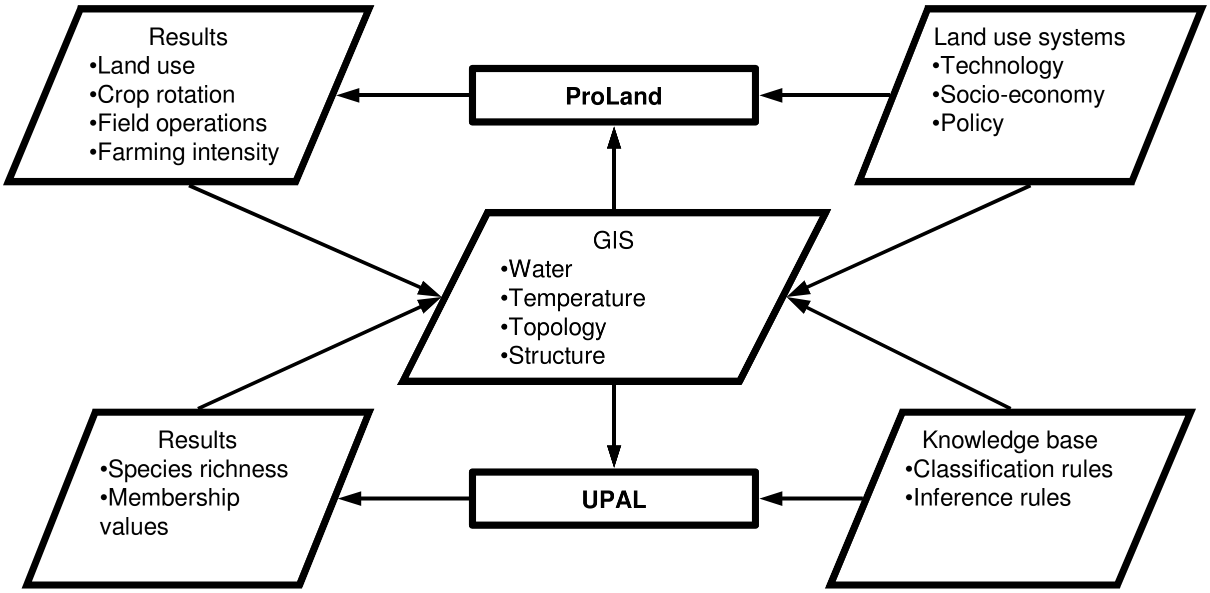
2.3. Connecting ProLand and UPAL

As previously elaborated, ecological models require spatially explicit information of varying complexity. Biodiversity models for agricultural areas should not only differentiate between different land uses such as arable farming or forest but also consider information concerning crop rotation, mechanization, and farming intensity. ProLand results contain such information on socio-economic but also technological attributes. All results can be joined to the respective decision units to generate maps of e.g. land rent, pesticide or fertilizer input, transfer payments etc.. UPAL processes information on natural, ecological, and technological attributes. Defuzzificated output is generated for the same decision units ProLand uses. Therefore, results can also be joined to decision units to create maps that contain information on changes of land use and species richness.

Prerequisite for such join operations is that each decision unit has a unique identifier. By linking the land use systems database and the results database to the GIS through this unique identifier UPAL can access ProLand results and land use systems data and process it as presented in section 2.2.

Illustration 4 shows the information flow between the two models. Data flows from the land use systems and GIS database into the model ProLand, is processed and the output stored in a results database. UPAL operates in a similar manner. This configuration enables both models to share results with other GIS based models.

Illustration 4 Information flow between UPAL and ProLand

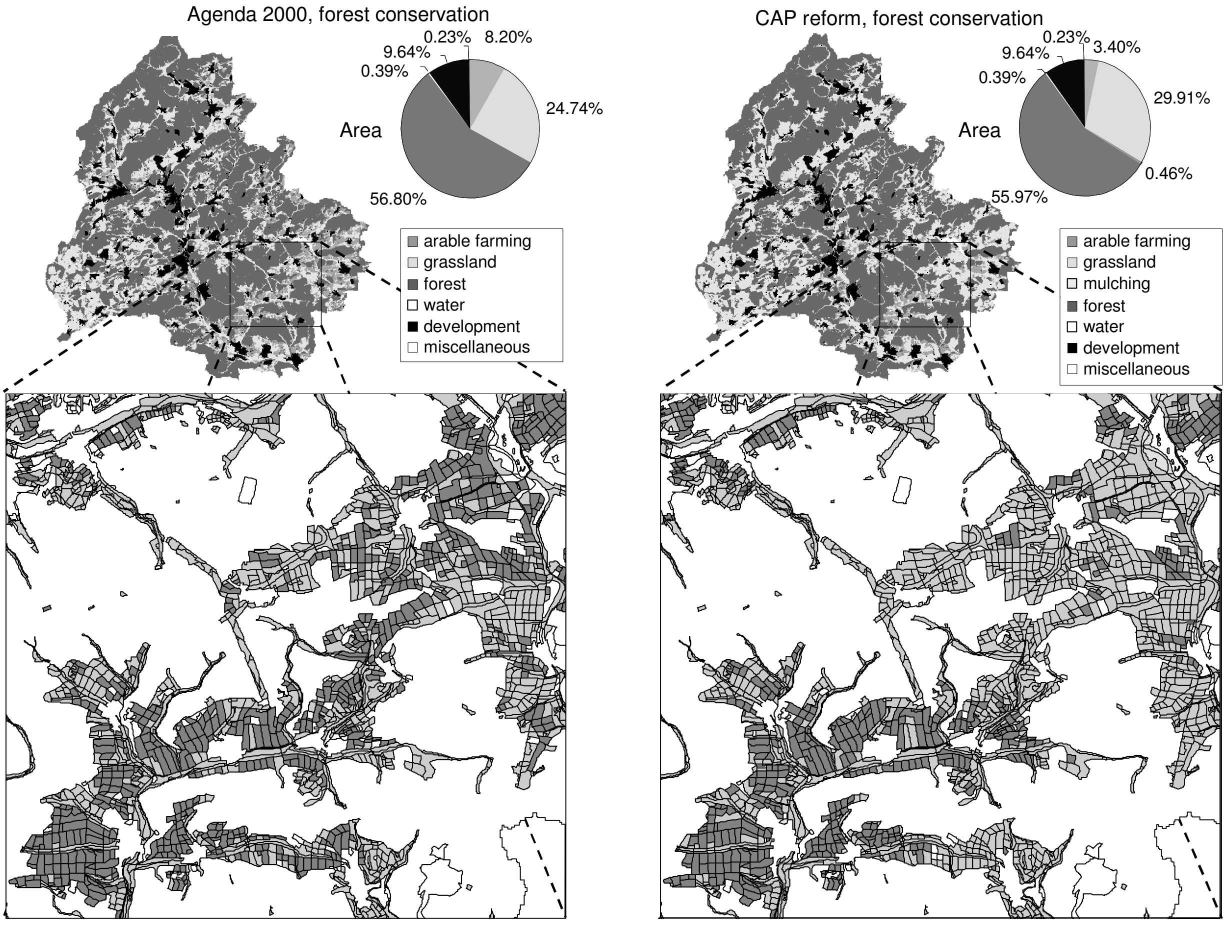


3. Results

ProLand generates spatially explicit data at various levels of detail. Land use maps are derived by assigning the land rent maximizing land use system to every decision unit. As all results generated by ProLand, they have to be interpreted as endpoints of adaptation processes. Comparing the land use and the land use systems employed in the two scenarios produces maps illustrating the differences between the long term land use predictions. Combined with maps of biodiversity indicators generated by UPAL they can illustrate potential effects due to changes of land use and / or land use systems.

About 55 % of the modeled region is used as forest in both scenarios. Legislative constraints protecting existing forests from clearing explain the high share of forest. Some new forest is predicted in the Agenda 2000 scenario. Contrary to the CAP Reform, no transfer payments are granted for mulching. With these payments mulching generates higher land rent than forest at certain sites which explains the lower share of forest. Under the Agenda 2000 about ¼ of the area is grassland used for dairy cows, and some suckler cows. Arable farming has a share of less than 10 %. The share of grassland is slightly higher under the CAP Reform at the cost of arable farming. Overall, the shares of the respective land uses show little change. However, sub-regions and intensity levels change considerably. Illustration 5 presents the predicted land use for both scenarios. As forest did not change in this sub-region it is dark gray in the overview map and left out in the magnification for clearer presentation.

Illustration 5 Predicted land use for Agenda 2000 and CAP Reform scenarios



The south-west quadrants of the lower maps show very little difference in land use contrary to the north-east quadrants. Here, a large share of land used for arable farming in the Agenda 2000 scenario is used as grassland in the CAP Reform scenario. At these sites precipitation is higher and temperatures lower than in the south-west quadrant. Commodity prices were only marginally lower in the CAP Reform scenario. Also, as subsidies were coupled to certain land use systems, they had a distorting effect on land users' factor allocations. Modifications of the transfer payment system may account for this land use difference. They induce land users to switch to extensive land use systems, predominantly extensive grassland. Illustration 6 supports this conclusion.

This specific area shows significant reactions to agricultural policy changes. The cultural landscape in the Agenda 2000 scenario is a mixture of arable and grassland farming systems. In the CAP Reform scenario, grassland becomes more dominant, affecting the landscapes aesthetic appearance. Other areas such as the region's south west (see overview in Illustration 5) remain mostly unchanged. Grassland dominates in both scenarios. Generalizing, fields are larger, precipitation is higher and temperatures are cooler than in the region shown in the lower two maps. Apparently, natural and structural conditions offset the effects of policy changes.

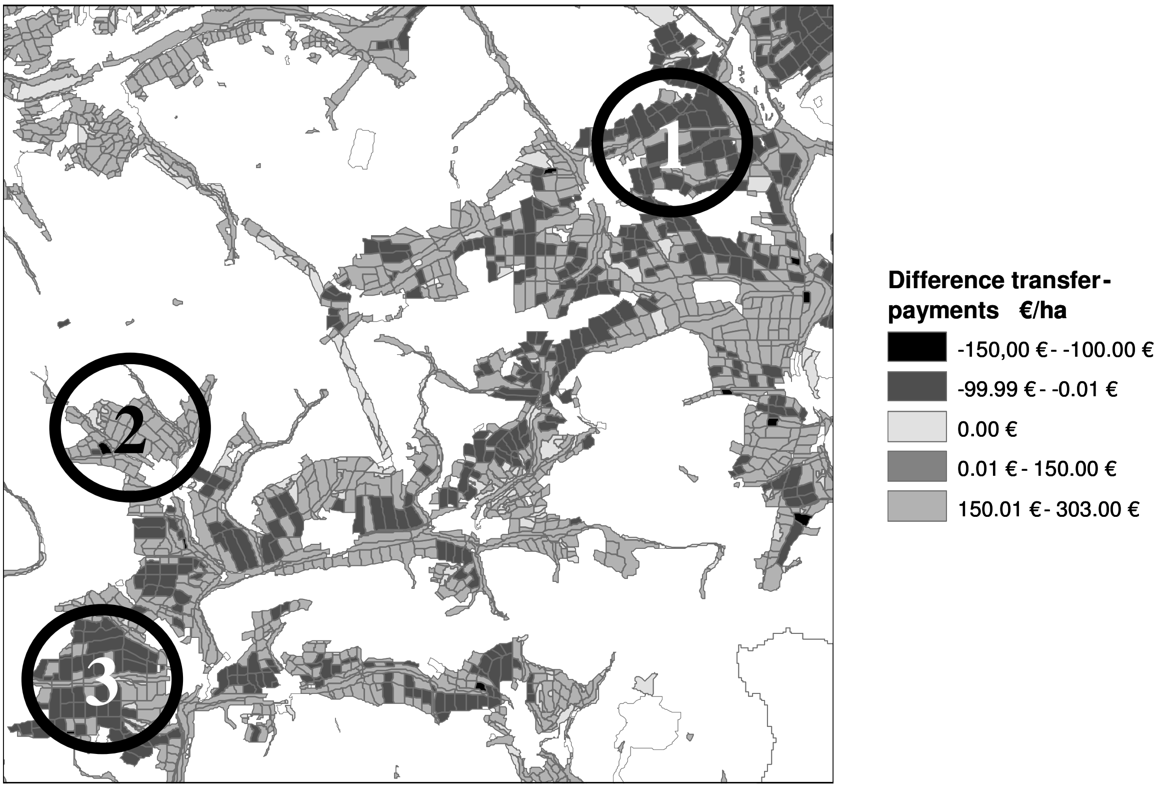
Table 2 lists selected key figures aggregated over the entire region. Land rent as a representation of a landscape's economic performance is significantly higher in the CAP Reform scenario than in the Agenda 2000 scenario. Transfer payments account for most of the difference. Labor input remains relatively constant. Overall, grassland's economic productivity is higher in the CAP Reform scenario, at the cost of arable farming.

Table 2 Key socio-economic indicators for Agenda 2000 and CAP Reform scenarios

land use	Agenda 2000			CAP Reform		
	land rent	coupled payments	labor input	land rent	decoupled payments	labor input
arable farming	2.913.787 €	1.740.208 €	181509 h	975.566 €	624.702 €	35953 h
grassland	9.121.083 €	1.062.489 €	663326 h	14.819.067 €	5.193.159 €	821591 h
mulching	0 €	0 €	0 h	77.830 €	88.805 €	216 h
forest	2.033.786 €	0 €	27987 h	1.655.507 €	0 €	22312 h
water	0 €	0 €	0 h	0 €	0 €	0 h
development	0 €	0 €	0 h	0 €	0 €	0 h
misc.	0 €	0 €	0 h	0 €	0 €	0 h
sum	14.068.656 €	2.802.697 €	872822 h	17.527.970 €	5.906.666 €	880072 h

The spatial distribution of transfer payments is heterogeneous. About 75 % of agricultural land receive more payments after the CAP Reform, 25 % get less. Illustration 6 shows the change of transfer payments from Agenda 2000 to CAP Reform per decision unit. Fields located in the north-east of the map (area 1) show differing land use in the two scenarios and receive less payments. Apparently, payments according to Agenda 2000 conditions cause arable farming to be more profitable than grassland. Fields located in area 2 receive more payments after the CAP Reform. These transfers may cause changes of intensity but not land use. Payments could be reduced to Agenda 2000 levels if the sole objective is to maintain a certain land use. Area 3 contains those fields that show the same land use in both scenarios but with reduced payments. Again, increasing transfer payments to previous levels may affect intensity only.

Illustration 6 Difference of transfer payments between Agenda 2000 and CAP Reform scenarios

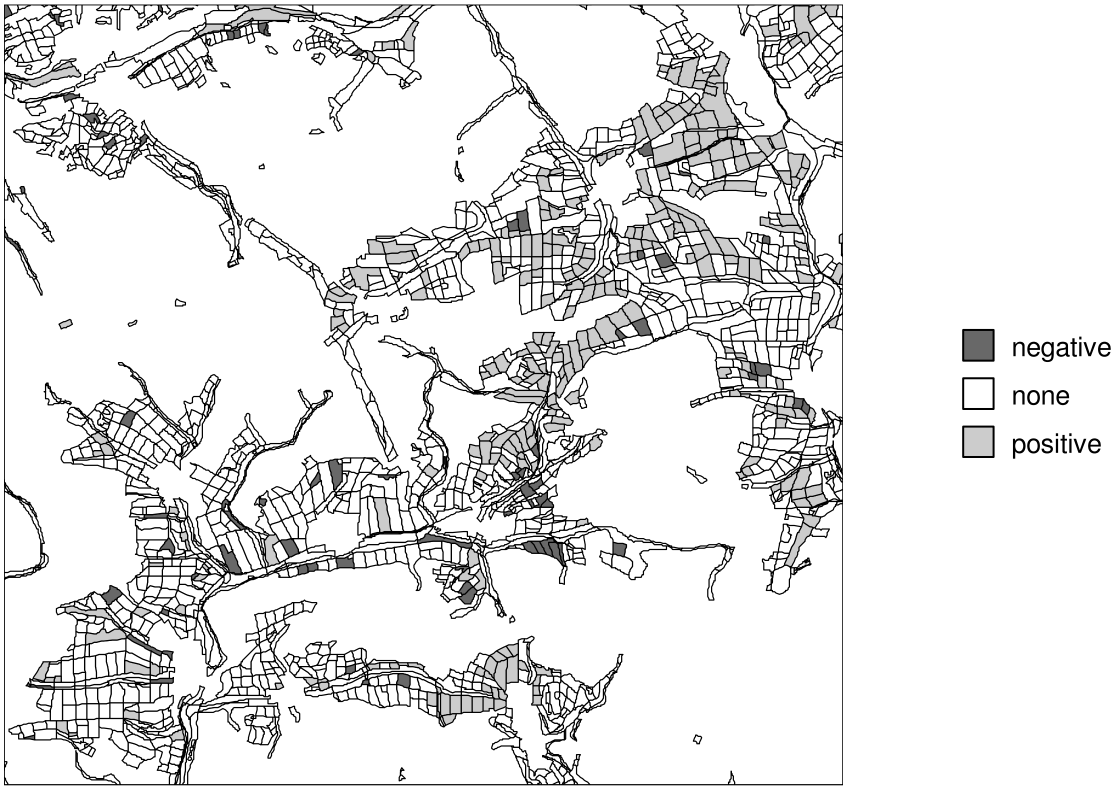


1 Acreages with different land use (Agenda 2000/CAP Reform) and reduced transfer payments
2 Acreages with identical land use (Agenda 2000/CAP Reform) and increased transfer payments
3 Acreages with identical land use (Agenda 2000/CAP Reform) und reduced transfer payments

The medial species richness assessed for the CAP scenario is 15 % higher than the assessed species richness for the Agenda 2000 scenario. Various reasons lead to this assessment. Most importantly, grassland replaces intensive crop rotations at numerous sites. Simulation results show that grassland area increases and arable farming area decreases in the CAP Reform scenario compared with the Agenda 2000 scenario. These land use changes mainly occur in areas used for arable farming in the Agenda 2000 scenario but with natural conditions favoring grassland. Intensive crop rotations include a routine application of herbicides. Obviously, this lowers the expected number of species on these sites. This may be the main cause for the forecasted increase of medial plant species richness. Another reason is a proportionate change from intensive to extensive grassland which only accounts for a medial increase of 0,4 %, however.

Illustration 7 presents the difference in species richness between Agenda 2000 and CAP Reform for the magnified region in illustration 5. Most fields show no difference in species richness. The north-east quadrant clearly shows a positive influence, however.. This is in line with the overall results as most fields in that area are predicted as grassland in the CAP scenario and arable land in the Agenda 2000 scenario.

Illustration 7 Difference in species richness between Agenda 2000 and CAP Reform scenarios



The overall increase is analyzed further with regard to land use differences on sites with a combination of ecological parameters favorable for species richness. Three combinations of ecological parameters were chosen. In addition to changes from arable farming to grassland changes from forest to grassland are important as well. In the present context this land use change is not influential regarding the medial change of species richness of arable fields and grassland in general. The CAP scenario forecasts a virtual decrease of forest compared to Agenda 2000. Virtual meaning land use changes from forest to grassland are only forecasted on sites were current land use is not forest, but would be forest in the Agenda 2000 scenario.

The area of extensive grassland increases on all assessed site types while the area of arable land declines as illustration 7, 8, and 9 show. Especially on dry acreages forest area declines. As forested area in the research region is much larger than that of other land uses, it is left out in the figures to realize a clearer presentation.

Illustration 8 Land use difference Agenda 2000 to CAP Reform on dry acreages

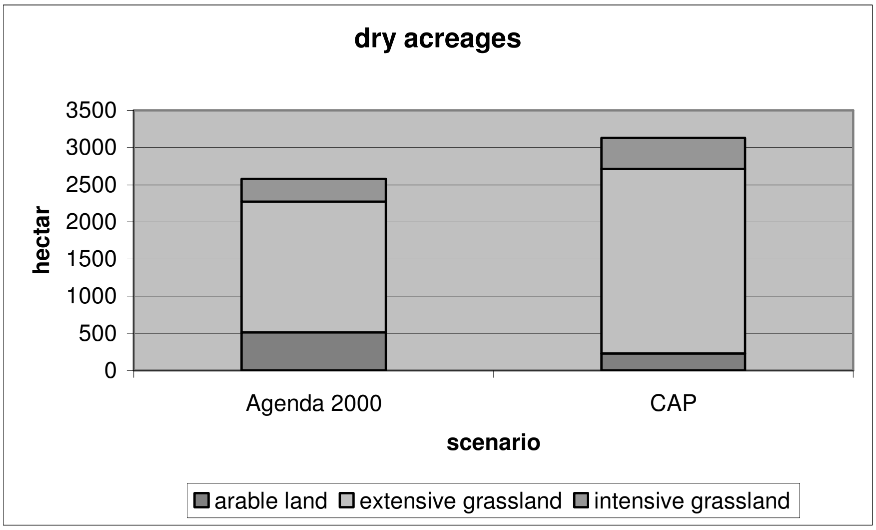


Illustration 9 Land use difference Agenda 2000 to CAP Reform on dry acreages, high insolation

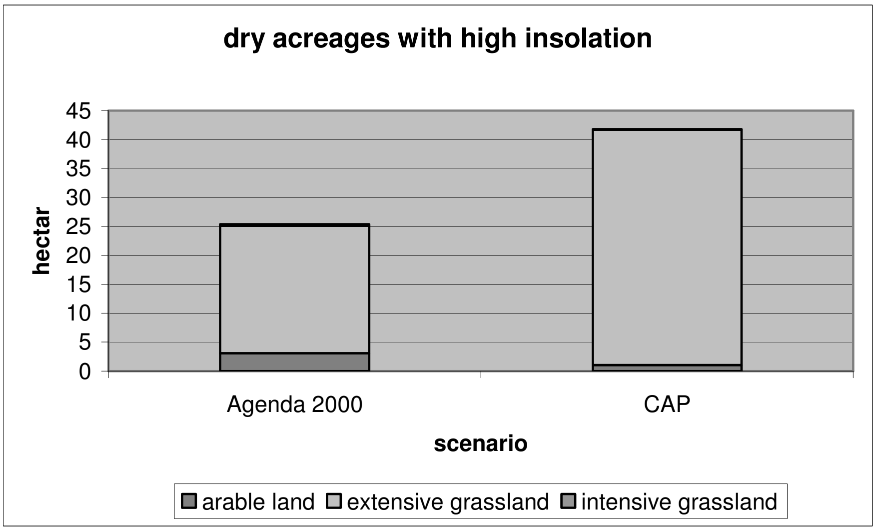
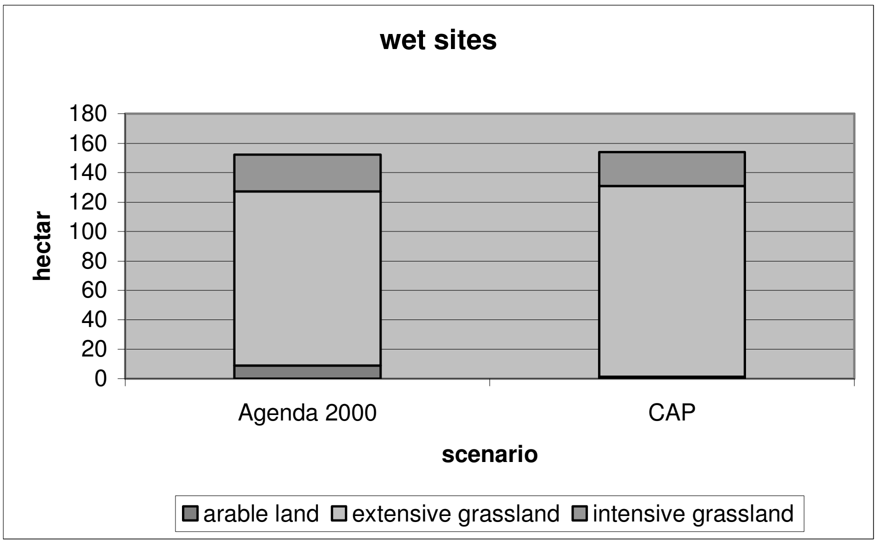


Illustration 10 Land use difference Agenda 2000 to CAP Reform on wet acreages



More extensive land uses on these ecological important sites lead to higher species richness because limiting impacts from land use decline. Illustration 8 shows the land use difference from Agenda 2000 to CAP Reform for sites with a membership value higher than 50 % for moisture class “dry”. The medial species richness increases 10.14 % on these sites under the CAP Reform. The sites with a membership value higher than 50 % for both moisture class “dry” and insolation class “high” shown in illustration 9 have an assessed increase of species richness of 3.39 % from Agenda 2000 to CAP Reform. This comparatively low increase traces back to the relatively large share of extensive grassland under Agenda 2000 already. Illustration 10 shows acreages with a membership value higher than 50 % for moisture class “wet”. The medial increase on these sites is 5.13 %.

Compared with the total increase of 15 % it is obvious that especially the change from arable land to grassland CAP Reform conditions is the main reason for the predicted increase of plant species richness of vascular plants.

4. Conclusions

Landscapes have to fulfill a multifunctional role. The CAP Reform’s “objectives include helping agriculture produce safe and healthy food, contribute to sustainable development of rural areas, and protect and enhance the status of the farmed environment and its biodiversity” (EU, 2004). The simulation runs indicate that the CAP Reform will assist in achieving these goals. Incentives to intensify production are removed as payments are no longer a function of product output. Instead, they are linked to multiple objectives such as environmental, food safety, animal and plant health and animal welfare, as well as the requirement to keep all farmland in good agricultural and environmental condition (“cross-compliance”).

The CAP Reform has positive effects on land rent, labor input and plant species richness in this less favored region. As output prices changed only by fractions of a percent, these effects are largely attributable to the decoupling of transfer payments. Extensive land use systems’ economic preferability increases in this region. Especially grassland systems profit. Contrary to the Agenda 2000 they receive decoupled area payments after the CAP Reform. Marginal sites such as dry sites with high insolation are not abandoned or afforested but kept in use as extensive grassland. As shown, specific sites used intensively under Agenda 2000 conditions are extensified. This extensification has a positive influence on plant species richness.

The described effects vary throughout the region. Some areas profit both economically in terms of land rent and ecologically in terms of plant species richness. Others show no change or are worse off in economic terms. Aggregated over the region results remain positive. There appear to be no major trade-offs between economic performance and ecological objectives. However, results do not necessarily apply to other regions. Especially regions with intensive arable farming may show different reactions in land use and species richness.

The scenarios illustrate the relevance of political factors in land use and biodiversity modeling. The approach allows to identify sensitive sites that show reactions in land use, farming intensity, and plant species richness. The research presented here is exemplary for the overall collaboration in the ITEEM model framework developed at the SFB 299 (cp. Bach, 2004). Results are available for other ecological, and hydrological models as well as evaluation concepts. The models' structures are such that new research results can be incorporated. Model transfer to other regions is subject of further research.

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