Land use and biodiversity: an indicator set supporting sustainable development

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Abstract

This paper reports findings of an interdisciplinary project aiming to assess the effects of agricultural policies on the environment and specifically on biodiversity. New developed biodiversity indicators were combined with an agricultural sector model (PASMA) to evaluate the effects of agricultural land use for Austria and its regions. In a case study a policy scenario with a reformed common agricultural policy (CAP) was simulated. The results show that farmers are likely to change intensity and types of land use. The effects of these land use changes on a set of biodiversity indicators for NUTS-3 regions are evaluated and discussed.

Keywords: land use modeling, agri-environmental programs, biodiversity indicators, agri-environmental indicators

1 Introduction

The main aim of the Convention on Biological Diversity (CBD), adopted by nearly all nations worldwide in Rio de Janeiro 1992, is to stop the world wide biodiversity decline. Nearly twenty years later this aim is still far from being reached. Biodiversity of the European Alps is not only characterised by the complex topography with wide bio-geographical gradients but also by a long lasting history of manifold anthropogenic land use. Protection of the natural resource biodiversity and its resulting ecosystem services not only is a desirable aim in itself, but seems to be a precondition for the welfare and a successful future development in this region.

In order to support policy makers to implement programs and policies that help to reach these objectives, it is necessary to show the concrete benefit of conservation measures. We focus on an interdisciplinary approach, structured in two main aspects: First, the provision of indicator sets which allow analyses of sustainable economic development in a spatial context to better understand, measure, and evaluate land use related phenomena. Second, the development and evaluation of policy relevant scenarios.

In this paper, we present an application of this new interdisciplinary approach in order to assess biodiversity effects of agricultural policy scenarios for Austria and its regions. The paper is structured as follows: we start with a short review of agri-environmental indicators and shortly describe their use in agricultural models. Next we focus on biodiversity indicators which were developed for interdisciplinary coupling with economic models. In the next chapter a case study is presented to show an application of these indicators in an agricultural sector model. The model and the policy experiment are described in more detail. The results of the policy scenarios are presented and the paper ends with a reference to biodiversity and a discussion about how well environmental indicators are related to environmental outcomes.

2 Agri-environmental indicators and programs

Several studies have shown significant impacts of agriculture on the environment. A broad coverage of such effects in the EU15 was recently presented by DG Environment (Baldock et al. 2000, 2002). These studies have explicitly taken into account environmental policy goals being integrated in the Common Agricultural Policy (CAP) from 1992 onwards.

Since 1992, member states have been legally obliged to implement agri-environmental programs that were co-financed by the EU. Policy makers acknowledged the fact that agriculture had been identified as a major cause of environmental degradation. This was also stated in the Fifth Environmental Action Program (Towards Sustainability), which addressed agriculture as one of the targeted sectors: changes in farming practices in regions of the EU have led to over-exploitation and degradation of the natural resources on which agriculture itself ultimately depends: soil, water and air (EC 1993).

A coherent way to evaluate the environmental improvements after policy reforms is monitoring by indicators. Apart from the work on environmentally harmful subsidies, the OECD has developed a set of internationally accepted environmental indicators. In the field of agriculture, the work on indicators has been fruitful and recent publications allow sound country comparisons (OECD 2001).

The OECD (2001) classified agri-environmental indicators according to the following categories:

- agriculture in the broader economic, social and environmental view with contextual information (like agricultural value added, farm employment) and information on farm financial resources (farm income, agri-environmental expenditures);
- farm management indicators of whole farms (organic farming, farm management plans), nutrient pest, soil, land, irrigation and water management;
- use of farm inputs and natural resources concerning nutrient use (nitrogen balance and efficiency), pesticide use and risk, and water use (water use intensity, water efficiency, water stress);
- environmental impacts of agriculture with respect to soil and water quality, land conservation, greenhouse gases, biodiversity, wildlife habitats, landscape and ecosystem diversity.

In the quantitative analysis presented in this paper we concentrate on indicators related to biodiversity, which has been identified above to be at risk in the EU due to intensive agricultural production. Consequently, biodiversity issues are frequently addressed by agri-environmental programs which are part of the program of rural development (PRD) in EU Member States.

3 Biodiversity indicators

Biodiversity is a complex and multidimensional concept (Purvis & Hector 2000; NOSS 1990). Hence, it cannot be described by a single number (Duelli & Obrist 2003). Many definitions of biodiversity differentiate between three different scales at which biological diversity may unfold: the genetic, the species and the ecosystem level. All those scales should be considered when describing biodiversity via indicators. Such an encompassing approach is very demanding and hard to implement in practical circumstances (Hermy & Cornelis 2000; Büchs 2003). Biodiversity indicators developed for management purposes have the explicit aim to simplify complex and hardly communicable relationships and interactions on the basis of scientific data and soundness. Therefore environmental indicators are so called boundary objects because they are used both, in the analytical context of natural science, and as a basis for decision making (cf. Star & Griesemer 1989). Consequently, we developed two complementary indicator sets based on wide and well funded ecological concepts and their corresponding database: naturalness and diversity of vascular plants.

3.1 Naturalness

Naturalness (N*d*) describes the anthropogenic influences of land use types and intensities (e. g. extensive and intensive grassland) on ecosystems (Rüdisser et al. 2011). It is an amplification of the hemoroby concept (cf. Steinhardt et al. 1999; Grabherr et al. 1998; Hill et al. 2002; Ferrari et al. 2008), which is mainly used to describe plant species and communities to reflect biodiversity relevant anthropogenic interference on ecosystems at the landscape scale. Indicator N*d* bases on a seven staged scale (1 = natural; 7 = artificial) with detailed descriptions of thresholds reflecting the assumption that anthropogenic caused biodiversity changes are mainly related to land-use changes (Rüdisser et al. 2011).

3.2 Diversity of vascular plants

Landscape-scale biodiversity is a function of land-use/land-cover changes. In order to take into account differences between land-use/land-cover (LULC) classes, estimates for plant species richness were introduced. In this way, the goal is not to represent the real species richness of a single landscape, but to provide a metric differentiation of the classes with floristic data. The differentiation was based on the data of Tasser et al. (2008) and Alexyova (2011) with 11,242 vegetation relevés (280 syntaxa): For each LULC class, relevés after Braun-Blanquet (1964) were taken from the phytosociological literature in order to derive 1) the mean species number and 2) the potential species pool. As mosses and lichens are often not recorded, only vascular plants were considered. The total species pool consisted of 2,750 vascular plant species, ranging from sub-Mediterranean forests to alpine grasslands.

In order to give consideration to different aspects of biodiversity, our indicators represent α- and γ-diversity. The area weighted mean plant species richness S_m (Tasser et al. 2008) takes into account how many species are found on average in the phytosociological records representing a LULC class. The spatial dominance of the classes is considered by area weighting. S_m can be considered as mean α-diversity within a sample unit. For an assessment of the γ-diversity we used the frequency weighted absolute plant species richness S_a introduced for analysis at the landscape scale by Tasser et al. (2008). It accounts for the potential occurrence of species and down-weights frequent species, thus considering relative rarity.

4 Land use modelling with PASMA

PASMA is a tool that has been developed for agricultural policy analysis and its effects in Austria (see Sinabell & Schmid 2006). It is a regionally disaggregated formal representation at NUTS-3 level of the Austrian agricultural sector. Compared to single farm models (e. g. Kirner 2002), PASMA results hold for the whole sector at regional and national scale and not for a representative number of farms only.

PASMA is employed to estimate the effects of agricultural policies on farm income, crop and livestock production, and farm labour at regional to national scales. Data from 'Allgemeines Land- und Forstwirtschaftliches Informationssystem' (ALFIS), the Integrated Administration and Control System (IACS), the Economic Agricultural Account (EAA) at NUTS-3 level, the latest agri-structural survey, the standard gross margin catalogue, and standard farm labour estimates (Greimel et al. 2002) provide necessary information on regional resource and production endowments. Calibration to observed production levels is achieved by applying the positive mathematical programming method (PMP, see Howitt 1995). Assumptions on future policies and forecasts of agricultural product prices are based on publicly available programme information and forecasts of OECD-FAO (2010).

In Austria, about 85% of all payments to farms come from three sources: direct payments (= single farm payment from 2005 on), the agri-environmental program ÖPUL, and the program for farmers in Less-Favoured Areas. Agri-environmental policies are of major significance for Austrian farming. This is best illustrated by the fact that the volume of such premiums (€ 645 million) exceeds the volume of direct payments (€ 500 million in 2004). Given their importance, not only instruments of the first pillar of the Common Agricultural Policy (CAP) are modelled in detail, but also second pillar policies dedicated to rural development objectives.

5 The policy experiment: a reformed common agricultural policy

To show the interaction between changes in the economic sphere, in particular the impact of agricultural policies, on the state of the environment, we analyse the effect of a reformed common agricultural policy on the agricultural sector in Austria. Given that farmers react on different market conditions and policy incentives, causal consequences on land use and thus biodiversity can be derived.

The two scenarios analysed in this paper differ from one another by the agricultural policy budget and its scope of measures:

- The baseline scenario is a situation based on previous studies (Sinabell et al. 2011). It assumes an unmodified continuation of the 2000–2006 programme of rural development with respect to the budget of € 1.02 billions p.a. and the scope of measures until 2020. Furthermore, it acknowledges the Health Check Reform of 2008, such as abolition of milk quotas, and agricultural market conditions as projected by OECD-FAO (2010).
- In the policy experiment a reformed CAP is simulated. The most important changes compared to the current situation and the baseline scenario are that decoupled farm payments are reduced by about 20%.
- Another difference to the baseline scenario is that selected measures of the agri-environmental program will be reduced, abolished, or become obligatory in order for farmers to qualify for decoupled farm payments, such as to plant winter cover crops on 70% of all arable land.
- In the policy scenario a situation is anticipated that will likely be relevant for farmers' decision making in Austria in 2020.
- In the model analysis the current and the likely situation are broken down to the regional scale (NUTS-3 level) in order to model a situation that is close to reality.

6 Implementation of the scenario and evaluation of effects on biodiversity indicators

The quantitative assessment of the scenarios was carried out by coupling the agricultural sector model PASMA with the indicator system for naturalness and vascular plant diversity at regional scales. The procedure to link the two models was the following:

- In a first step, the baseline scenario was defined. PASMA was calibrated to reflect the production and policy situation after the CAP reform in 2008 and before the implementation of a new CAP.
- Based on forecasts about economic developments and agri-environmental policies, economic results for 2020 were derived for both scenarios.
- The effects of these policies such as the effects of price changes on agricultural land use were quantified at NUTS-3 level. These results were used in the biodiversity module to quantify the effects on biodiversity indicators based on the division of PASMA land use classes. As PASMA only includes agricultural and forestry land use types, only those areas were considered.

7 Results and discussion

In the scenarios that are compared for this analysis, external market conditions (mainly prices) are the same, so it is possible to isolate the effect of the policy change. The changes of agricultural policy have considerable impacts on the agricultural sector (farm income, production structure, level of input use and output level). Assuming the market conditions and policy environment as described (reformed CAP) the following effects are to be expected (Table 1):

- Farming will become less profitable and forest land will be expanded (+3%) at the costs of agricultural land (mainly extensive grassland and marginal arable land) and, consequently, this leads to lower farm incomes (appr. 5%).
- The level of subsidies is significantly lower (more than 20%) in the policy scenario compared to the baseline scenario.
- According to the model results farmers will compensate the loss of subsidies by producing at a higher level of intensity (+1% of average nitrogen intensity (kg ha^{-1} farm land)) with considerable variation among NUTS-3 regions, but nevertheless farm output will decline (by 2%).
- The area for organic farming will be reduced (by 3%).

Summing up we would expect that on one hand agricultural land will be reduced and mainly substituted by forests while on the other hand farming on the remaining agricultural land will become more intensive. This is reflected by the indicators nitrogen intensity (kg N ha^{-1}) (going up) and area under organic farming (going down).

Effects of land use changes on biodiversity at NUTS-3 level were analysed using the indicators naturalness and diversity of vascular plants. In the long run the expansion of forested land caused by the abandonment of agricultural land will result in an increase of mean vascular species number and an increased naturalness (Figure 1: Map 1 & 2) at the landscape level. These effects are dominant in regions with high shares of arable land. In the alpine region of Austria the consequences of these effects are much smaller. Forests in these regions would substitute relatively natural land use types with above-average species numbers (e. g. extensively used grasslands).

The increased intensity (see nitrogen use in Figure 1: Map 3) or a decrease of organic agricultural areas (see Table 1) on the remaining farmland has negativ effects on the (local) agri-environmental situation and could cause a deterioration or even loss of ecological valuable land use types (e. g. larch meadows). This effect is also reflected by a decrease of S_m and an increase of N*d* if calculated for agricultural used areas only (Table 1) and is most pronounced in NUTS-3 regions that have a large share of (extensively used) grassland.

Concerning the interpretation of the results, one has to bear in mind that the state of the environment does not change as swiftly as market and policy conditions do. An improvement of the state of the environment needs years and decades, until a new equilibrium state is achieved. It is evident that land that was used very intensively for agricultural production, will pass through a series of successional states if it is turned to fallow land and gradually becomes a forest. This process lasts for years.

Decreasing agricultural subsidies will not necessarily lead to decreasing biodiversity levels in all regions, as often assumed. On the contrary, an expansion of natural forest habitats in intensively used agricultural landscapes could lead to an improvement of the environmental situation of this region. Whether the change of agricultural land to forest is a desired option from a social, cultural or landscape aesthetical point of view is a question that has to be discussed separately.

Table 1: Comparison of indicator results for the baseline scenario and the scenario with a reformed CAP in 2020; S_m = mean vascular plant richness; Nd = naturalness (remark: decrease of Nd = increase in naturalness).

	Differences (%) in						
Region (NUTS-3)	**farm income**	**farm output**	**agricult. used area**	**ext. agri-cult. used area**	**area with organic farming**	**S_m on agri-cult. used area**	**Nd on agri-cult. used area**
Mittelburgenland	−7.2	−3.5	−6.2	−7.9	−2.2	0.05	0.07
Nordburgenland	−5.5	−1.5	−3.2	−0.9	−0.3	0.12	0.06
Südburgenland	−7.5	−3.8	−7.4	−7.2	1.7	0.00	−0.01
Mostviertel-Eisenwurzen	−3.4	−1.1	−2.7	−2.6	−2.4	2.91	−2.24
Niederösterreich	−5.5	−2.3	−5.6	−5.0	−2.8	2.76	−2.71
Sankt Pölten	−4.3	−1.5	−3.2	−2.4	−1.1	2.78	−2.43
Waldviertel	−4.8	−2.8	−3.6	−3.2	−0.8	−0.33	0.05
Weinviertel	−7.0	−2.5	−4.2	−2.5	0.7	0.03	0.03
Wiener Umland/Nordteil	−6.5	−3.2	−4.5	−1.9	2.7	0.02	0.00
Wiener Umland/Südteil	−7.4	−3.1	−6.1	−3.7	0.6	0.16	−0.12
Wien	−4.8	−2.1	−4.7	−3.6	−0.5	0.11	0.13
Klagenfurt-Villach	−5.3	−2.5	−3.8	−3.3	−5.0	0.37	−0.47
Oberkärnten	−6.5	−2.8	−4.6	−4.7	−3.5	−1.40	1.09
Unterkärnten	−4.7	−1.9	−3.2	−3.4	−2.7	1.58	−1.83
Graz	−4.8	−1.8	−3.2	−2.4	−5.4	3.11	−2.13
Liezen	−4.8	−1.2	−7.7	−10.6	−3.4	−0.70	0.49
Östliche Obersteiermark	−5.7	−2.5	−6.3	−7.3	−4.1	−0.88	0.47
Oststeiermark	−3.5	−1.1	−3.0	−2.6	−4.1	2.56	−1.95
West- und Südsteiermark	−3.5	−1.4	−2.6	−2.5	−2.5	3.54	−2.45
Westliche Obersteiermark	−5.9	−2.4	−7.4	−9.5	−1.9	−0.86	0.19
Innviertel	−4.3	−1.0	−2.6	−2.3	−2.7	1.27	−0.70
Linz-Wels	−4.9	−1.3	−2.3	−2.0	−1.2	0.06	−0.07
Mühlviertel	−5.7	−2.9	−4.2	−2.6	−1.1	0.66	−0.73
Steyr-Kirchdorf	−4.3	−1.0	−3.5	−3.0	−4.2	4.35	−3.34
Traunviertel	−4.0	−0.8	−3.7	−3.7	−5.0	−0.10	−0.45
Lungau	−5.2	−1.9	−5.3	−4.8	−1.9	2.04	−2.14
Pinzgau-Pongau	−5.6	−1.9	−1.8	−1.0	−2.8	−3.40	2.85
Salzburg und Umgebung	−3.8	−1.0	−4.0	−7.4	−1.8	−3.53	1.47
Außerfern	−4.1	−1.1	−2.7	−3.0	−4.1	−0.75	0.45
Innsbruck	−3.7	−1.3	−2.8	−3.1	−4.3	−1.39	1.30
Osttirol	−5.7	−2.2	−3.9	−4.0	−3.6	−2.55	2.23
Tiroler Oberland	−5.4	−1.9	−2.7	−2.6	−2.9	−2.60	2.23
Tiroler Unterland	−4.3	−0.9	−5.2	−5.8	−2.5	−2.92	2.50
Bludenz-Bregenzer Wald	−2.9	−0.9	−1.3	−1.3	−3.6	−1.65	1.69
Rheintal-Bodenseegebiet	−2.6	−1.0	−1.3	−1.1	−2.9	−1.19	0.46

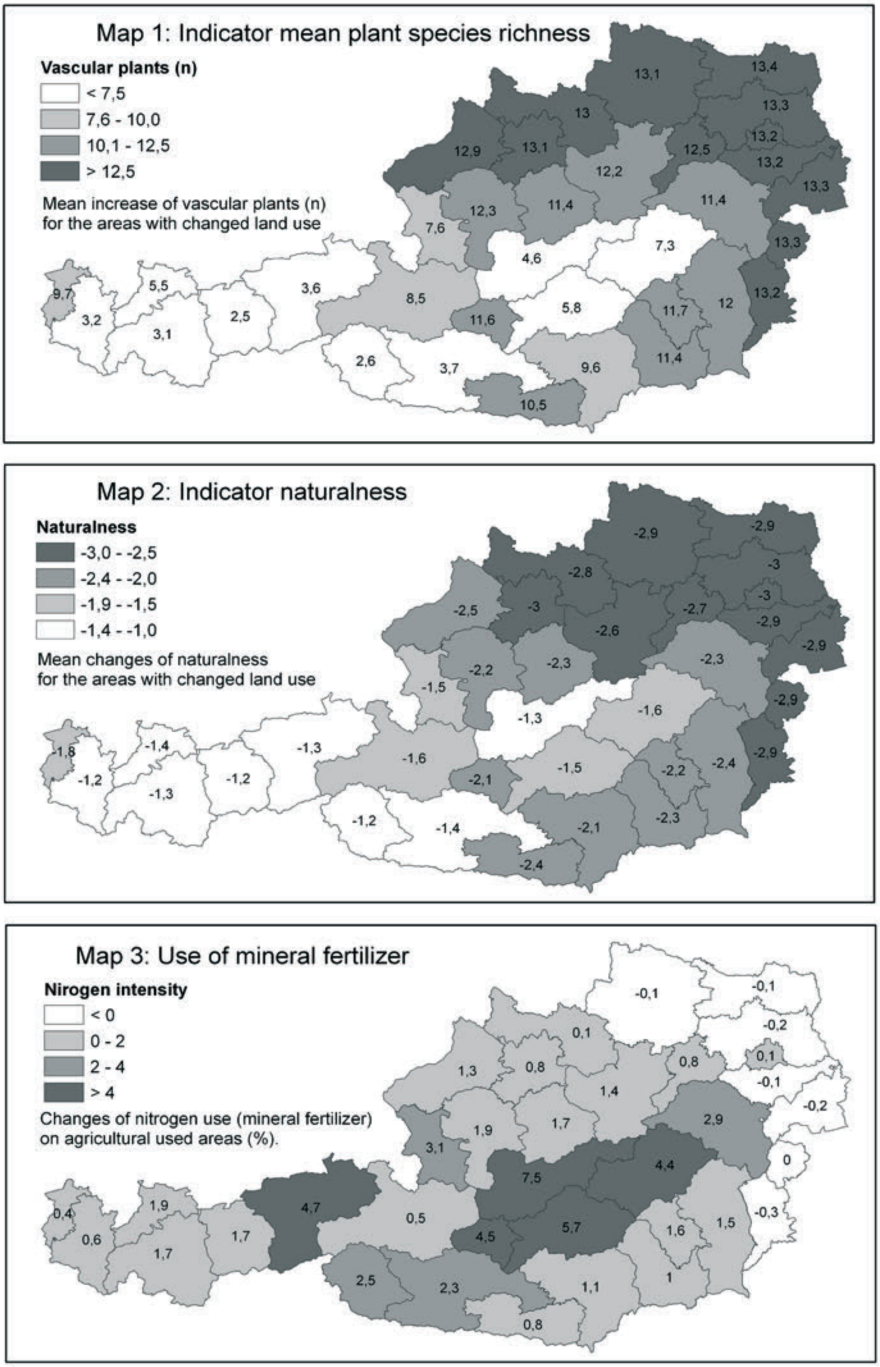

Figure 1: Map 1 and 2 show the changes for the indicators mean vascular plant richness and naturalness for the areas affected by land use changes. Map 3 shows the changes of mineral fertilizer use on agricultural used areas (in %).

The indicators discussed here focus on the landscape scale and do not evaluate effects of specific and detailed agri-environment measures at a local scale. This is an option for further analyses. We think it is important to acknowledge these limitations in order to prevent misinterpretation of the results presented here. We believe that the approach presented in this paper and the methods and tools to describe the complex interaction between the economic and the ecological sphere are promising. In a next step a further refinement, focusing on a better spatial resolution of the results of the PASMA-simulation from NUTS-3 to a 1 km² raster, is planned. This will allow the application of further indicators (e.g. absolute plant species richness) which are not suitable at the NUTS-3 level, and helps to gain further insights and deeper understanding about the interaction between economic incentives and agri-environmental outcomes.

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