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Expert knowledge-based assessment of farming practices for different biotic indicators using fuzzy logic

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ABSTRACT

The study presented here describes a modeling approach for the ex-ante assessment of farming practices with respect to their risk for several single-species biodiversity indicators. The approach is based on fuzzy-logic techniques and, thus, is tolerant to the inclusion of sources of uncertain knowledge, such as expert judgment into the assessment. The result of the assessment is a so-called Index of Suitability (IS) for the five selected biotic indicators calculated per farming practice. Results of IS values are presented for the comparison of crops and for the comparison of several production alternatives per crop (e.g., organic vs. integrated farming, mineral vs. organic fertilization, and reduced vs. plow tillage). Altogether, the modeled results show that the different farming practices can greatly differ in terms of their suitability for the different biotic indicators and that the farmer has a certain scope of flexibility in opting for a farming practice that is more in favor of biodiversity conservation. Thus, the approach is apt to identify farming practices that contribute to biodiversity conservation and, moreover, enables the identification of farming practices that are suitable with respect to more than one biotic indicator.

1. Introduction

Agricultural fields provide habitat to a large number of different flora and fauna species (Stoate et al., 2001). Thus, farming activities performed on agricultural fields have significant effects on the habitat quality within the agricultural landscapes, especially when agricultural fields and natural or semi-natural areas are spatially closely intertwined. The side effects on the habitat quality that go along with farming activities can be either positive (e.g., provision of food resources by the main crop or accompanying under-sown crops or intercrops in the rotation), or negative (e.g., direct killing or impairment of species populations by different operations, such as mowing or pesticide spraying). Against this background, an ex-ante assessment approach that provides information about which farming activities will contribute to biodiversity conservation in agricultural landscapes and those which pose a threat to biodiversity would be very useful if we want to integrate conservation issues into modern agriculture and chose in favor of more environmentally-friendly farming practices.

In the literature, different approaches for the ex-ante assessment of farming practices are described, mostly relying on quantitative data. Andersen et al. (2000), for instance, employed tree regression models to analyze the habitat requirements of threatened desert tortoises. The statistical model was based on a combination of field data and data derived from various spatial databases, including satellite imagery. As another example, Llusia and Onate (2005) did an ex-ante assessment of the adequacy of agri-environmental schemes toward the habitat requirements of pseudo-steppe birds. For the assessment, they first identified 21 'desirable agricultural practices' and then determined the degree to which these practices are included among the schemes' commitments. And Primdahl et al. (2010) analyzed the use of input models with respect to agri-environmental programs in supporting environmentally-friendly farming practices. Impact models identify and establish the causal relationships between policy objectives and policy outcomes. They can be quantitative or qualitative in nature. However, according to Primdahl et al. (2010) quantitative models are less common where biodiversity is concerned.

This is mostly due to the fact that inter-dependencies between agricultural activities and the biotic environment are highly complex and not fully understood to date. So one basic problem lies in the uncertainties we have to deal with if we want to describe them. This is particularly true for agricultural systems, as ecological, technical, and socio-economic systems are interacting, and quantitative data and secure information are not always available (e.g. Leeuwis, 2004; OECD, 1997). Necessarily, assessments in this

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context have to deal with uncertainties and should make the best use of the information available, including qualitative information.

Thus, this study aims to introduce a modeling approach for the ex-ante assessment of different farming practices for different biotic indicators that is tolerant of qualitative information. The approach employs fuzzy-logic techniques, which explicitly recognize uncertainty and, thus, enables the integration of sources of uncertain knowledge, such as expert judgment, into the assessment (Prato, 2007; Lotfi and Howarth, 1997). The concept of fuzzy logic has been proven a suitable concept for assessments under uncertainties and has been applied in numerous studies dealing with model-based ecological impact assessment (e.g., Mitra et al., 1998; Van der Werf and Zimmer, 1998; Mertens and Huwe, 2002; Daunicht et al., 1996).

The study is structured as follows. Firstly, in Section 2, the methodology is described. Secondly, in Sections 3 and 4, the results are presented and discussed. The study closes in Section 5 with the conclusions.

2. Methodology

2.1. Evaluated farming practices

The basis for the evaluation of farming practices in this work is the collection of farming practices of the modeling system MODAM (Multi-Objective Decision support system for Agro-ecosystem Management) that was defined for the climatic conditions of North-eastern Germany. MODAM is a micro-economic farm model that was developed by Zander and Kächele (1999). The farming practices of MODAM offer a detailed description of each work step, that is, seed bed preparation, sowing, fertilization and pesticide treatments, mechanical weeding and harvesting, which is necessary to grow a certain crop on a site with a given yield potential. The per work step data are provided regarding the type and amount of inputs, the timing, the frequency of operations and the type of machinery used. All of this information was gathered from land use statistics, standard data tables on farming techniques and from agronomic experts (Zander, 2003; Bachinger and Zander, 2007). Altogether, the database contains 327 farming practices differentiated for four soil qualities defined for approximately 20 crops. For each crop, a so-called 'standard variant' is described that reflects the most prevalent way the respective crop is grown in a certain region. Furthermore, several alternative farming options, such as for organic farming, reduced tillage, reduced fertilization, and delayed mowing, are available. As an example, Table 1 shows the description of the standard variant for winter rye production.

For each work step, a working period is assigned, during which the operation is usually performed. The data were derived from standard data collections (KTBL, 2008). Thus, the farming practices in MODAM do not represent actual practices that refer to a concrete year with specific dates for each operation; rather, they typify the average farming practices that are valid under yearly deviant weather conditions and that can be used for ex-ante assessment. Furthermore, the kind of input is specified per work step. The frequency describes how often the work step is performed during the assigned working period. Frequencies below one can be interpreted in two ways: either the work step is not performed on the whole area (e.g., the pesticide treatments of weed nests), or the work step does not take place every year (e.g., liming). The amounts are given for the product volumes that should be bought. For each operation, the kind of machinery (i.e., the power class of tractor and the type of attachments and their working width) is also specified (this information is not presented in Table 1).

2.2. Selection of the biotic indicators

The aim of the approach was to assess the farming practices of MODAM in regard to different biodiversity issues. As relations in agro-ecosystems are manifold and highly complex, an assessment of all of the elements is impossible, thus, suitable indicators had to be selected. For this study, single-species indicators were chosen that represented certain groups of species typical for agricultural landscapes (Stachow et al., 2002). Overall, five indicators were identified that use agricultural fields as their main or complementary habitat: wild flora species for primary producers, hover fly (*Syrphidae*) for beneficial pollinating insects, red belly toad (*Bombina bombina*) for amphibians, skylark (*Alauda arvensis*) for field-breeding birds, and field hare (*Lepus europaeus*) for mammals. The indicator selection aims to include several species that cover different ecological niches and positions within the food chain in agricultural landscapes. This approach follows the so-called 'multi-taxa' or 'shopping basket' approach (Vane-Wright et al., 1994; Kotze and Samways, 1999). While single species may fail to serve as a surrogate for overall biodiversity a selection of a set of taxa with

Table 1
Description of the standard farming practice for winter rye production in MODAM.

No.	Work step/operation	Working period		Inputs	Frequency[a]	Amount[a]
		From	To			
1	Chisel plowing	21.07.	31.08.	–	1	0.00
2	Mineral fertilizer application	21.07.	31.08.	Phosphate (100% P_2O_5)	1	21.59
3	Mineral fertilizer application	21.07.	31.08.	Potash (100% K_2O)	1	58.46
4	Mineral fertilizer application	21.07.	31.08.	Lime (100% CaO)	0.25	1000.00
5	Loading of mineral fertilizer	21.07.	31.08.	–	1.25	0.00
6	Plowing	01.09.	01.10.	–	1	0.00
7	Seed bed preparation	01.09.	01.10.	–	1	0.00
8	Sowing of cereals	15.09.	15.10.	Winter rye (seeds)	1	100.00
9	Mineral fertilizer application	16.03.	05.05.	Nitrogen (33.3% N)	2	150.15
10	Loading of mineral fertilizer	16.03.	05.05.	–	1	0.00
11	Herbicide application	16.03.	05.05.	Grass weeds	1	1.00
12	Fungicide application	06.05.	04.07.	Mildew, septoria	1	1.00
13	Growth regulator application	06.05.	04.07.	Retardation cereals	0.5	1.00
14	Straw fertilization	21.07.	31.08.	–	1	0.00
15	Harvesting of cereals	21.07.	31.08.	–	1	52.29
16	Grain drying	21.07.	31.08.	–	1	0.00
17	Grain transportation	21.07.	31.08.	–	1	0.00
18	Grain placement into stock	21.07.	31.08.	–	1	0.00
19	Yield	21.07.	31.08.	Winter rye (product)	1	52.29

[a] Frequency and amounts are related to sites with medium yield expectations.