

An expert system for integrating biodiversity into agricultural life-cycle assessment



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ABSTRACT

Decision-making for nature-friendly land use in farming landscapes requires methods and indicators for assessing effects on biodiversity. We developed an expert system for including biodiversity (i.e., organismal diversity) as a life-cycle assessment (LCA) impact category in agricultural production. The method developed is valid for grasslands, arable crops and semi-natural habitats (SNHs) of the farming landscape, and allows us to estimate the impact of management systems on biodiversity. Eleven indicator-species groups or ISGs (flora of crops and grasslands, birds, mammals, amphibians, snails, spiders, carabids, butterflies, wild bees, and grasshoppers) were selected on the basis of ecological and life-cycle assessment criteria. Inventory data on crops, SNHs and agricultural practices with detailed management options were specified. A scoring system estimating the suitability of the farmland crops and SNHs as habitats as well as the reaction of each indicator-species group to the management options was developed. A case study calculated biodiversity scores for grassland along an intensity gradient, as well as those for winter wheat in the case of various cropping systems. The results allowed us to identify management options expected to have a major impact on biodiversity. The number of species observed during a plant and grasshopper survey showed high correlations with the scores derived from the detailed management activities. The use of 11 indicator-species groups allowed a differential, comparatively comprehensive assessment of the impacts of the agricultural practices on biodiversity. Production systems can be compared in terms of their potential impact on biodiversity, which may in turn enable us to make recommendations for good practice. We conclude that the expert system can also be used to investigate land-use scenarios at farm level, as well as on a regional scale.

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1. Introduction

The impact of agriculture on the environment, including biodiversity issues (e.g. Benton et al., 2002; Burel and Garnier, 2008; EEA, 2007; McNeely et al., 1995; Reidsma et al., 2006; Tschardt et al., 2005), has been the subject of public debate for several decades now (e.g. Matson et al., 1997; UNEP, 2010). Following the concern of governments and international organisations, the question arises as to how to maintain or even restore biodiversity in intensively managed agricultural landscapes. The first step in achieving this goal is undoubtedly to recognise and quantify the impact of agricultural practices on biodiversity,

followed by a promotion of best practices. Numerous publications and reviews (e.g. Burel and Garnier, 2008; Stoate et al., 2001) describe the impact of modern agricultural practices on biodiversity. As with other environmental issues, however, governments and organisations often require simple, aggregated and communicative models and indicators that summarise situations, such as the Swiss Bird Index SBI[®] (Zbinden et al., 2005) and the farmland bird index as a broad geographic range indicator (BirdLife International, 2004). Such expert systems and models, including a comprehensive set of agricultural practices and an assessment of the impact on biodiversity, have either simply not yet been developed (Bockstaller et al., 2009, 2008), or have focused on specific groups of species, agricultural practices or production systems (e.g. Mineau and Whiteside, 2006; Pervanchon, 2004; Schippers and Joenje, 2002). Decision-making also requires several environmental impacts of human activities to be taken into account simultaneously – hence the development of the life-cycle assessment (LCA) method. LCA allows to compare the range of

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environmental impacts like e.g. the global warming potential, the ozone formation, the terrestrial ecotoxicity, the energy demand, that can be attributed to products. In the case of agricultural processes, however, certain adjustments of this method are necessary. Particularly indispensable is the inclusion of new core agricultural impact categories, e.g. soil quality, farmland biodiversity and the landscape.

The necessity of incorporating biodiversity and/or land use as impact categories in LCA methodologies has long been recognised (SETAC/UNEP LCA initiative, Jolliet et al., 2003; Milà i Canals et al., 2007), and the state of the art has been summarised in recent reviews (Curran et al., 2011; Koellner and Geyer, 2013; Lenzen et al., 2007). Two approaches to evaluating the effects of agricultural activities (as construed in a broad sense) on biodiversity are found in the literature. The first approach performs an environmental diagnosis based on a biotope evaluation with indicators (“ecological value” of farms, e.g. Brosson, 1999; Frieben, 1998). The second shows how biodiversity can be included in LCAs as a mid-point impact category like other categories such as global-warming potential. Based essentially on the biodiversity of vascular plants (Tracheophytes), this approach includes the impact of industry, agriculture and transport on a continental scale (e.g. Köllner, 2000; Lindeijer et al., 1998; Milà i Canals et al., 2007; Müller-Wenk, 1998), as well as evaluating the rarity and vulnerability of the ecosystems (Weidema and Lindeijer, 2001). Furthermore, studies have shown how biodiversity can be integrated into LCA on a global scale by investigating the impact of land use on the species richness of different land-use types compared to a (semi-) natural regional reference situation (Biodiversity damage potential, de Baan et al., 2013), or by applying concepts of ecosystem scarcity, vulnerability, and conditions for maintaining biodiversity (Michelsen, 2008) in the specific case of forestry. Penman et al. (2010) have highlighted the main problems of these approaches, e.g. the difficulty in agreeing on surrogates for biodiversity.

Based on the second approach, we developed an expert system for evaluating the impact of agriculture on biodiversity with two characteristics distinguishing it from methods published to date:

- A detailed focus on crops and semi-natural habitats (SNHs: those habitats not primarily devoted to production, e.g. extensively managed and low-input meadows, wildflower strips, hedges) of the farming landscape, and farming practices. This method is designed for use in combination with conventional mid-point life-cycle impact assessment (LCIA) methods (see for example, Nemecek et al., 2005).
- A thorough consideration of species groups whose diversity is affected (i.e. flora and fauna), the present parameterisation being valid for use in Switzerland and neighbouring regions. Although complex biodiversity in the broadest sense of the Rio Convention cannot be fully measured as such, a single indicator is unlikely to reflect the complexity of agro-ecosystems (e.g. Büchs, 2003). Instead, groups of indicators that are sensitive to environmental conditions resulting from land use and farming activities are selected, and give as representative a picture as possible of biodiversity as a whole.

To insure further use of the expert system as a tool of the LCA methodologies, the development of the method followed the standard development of indicators in LCA as for other impact categories: (i) conceptual approach and framework; (ii) literature and expert consultation; (iii) model building; (iv) sensitivity analysis; (v) plausibility test; and (vi) (partial) validation.

The aim of the expert system presented here is to estimate and compare the impact of farming systems on biodiversity using a set of indicator-species groups. In a case study, the results of the application of the method to several production systems

representing field-management options for grassland (intensity level) and wheat (cropping system) were calculated by way of illustration. In addition, a sensitivity analysis was used for each indicator-species group to gauge the influence of the main farming practices within the expert system calculation (factors prioritization setting, Cariboni et al., 2007), e.g. fertilisation, mowing. Next, a validation with plants and grasshoppers was performed in 2008 with data from grassland systems collected in situ. In point of fact, vascular plant diversity correlates well with the overall biodiversity of a region (Duelli and Obrist, 1998), and grasshoppers (Orthoptera) are typical grassland insects, 80% of whose species in Switzerland occur in meadows and pastures (Schneider and Walter, 2001). Both indicator groups are relatively easy to record and identify, and react sensitively to agricultural practices (e.g. Marini et al., 2008).

2. Materials and methods

2.1. Indicator-species groups

The issue of biodiversity indicators in agriculture has been the subject of discussion since the 1990s, and reports have established sets of indicators to be monitored in Europe (Billeter et al., 2008; Burel and Garnier, 2008 for a review; EEA, 2007; Herzog et al., 2013). The choice of biodiversity indicators depends primarily on the objects of the study (Huston, 1994; Noss, 1990). For the present method, the choice of indicator-species groups (ISGs) was made using a criteria table (Appendix A, Table A.1) taking into account the relationship between ISGs and agricultural activity (Jeanneret et al., 2006), as well as general criteria such as ISG distribution, habitats, and level in the food chain as recommended by the authors (Pearson, 1995; Reid et al., 1993; Stork and Samways, 1995; UNEP, 2003). Indicators must make it possible to estimate the impact of agricultural activity at plot and farm level, since biodiversity in the cultivated landscape is influenced by local (e.g. crop management method, Burel and Garnier, 2008; Ewald and Aebischer, 2000; McLaughlin and Mineau, 1995) and landscape factors (e.g. number of semi-natural habitats, Bailey et al., 2010; Duelli, 1997; Jeanneret et al., 2003; Tscharncke et al., 2005). The indicators selected must also provide as representative a picture as possible of organismal diversity as a whole. Although recognised as a highly important habitat for biodiversity and known to support major functions, soil and soil organisms were not taken into account in this method (but see Oberholzer et al., 2012). The following ISGs were then selected: vascular plants (grassland and crop flora), birds (Aves), small mammals (Mammalia), amphibians (Amphibia), snails (Gastropoda), spiders (Araneae), carabid beetles (Carabidae), butterflies (Rhopalocera), wild bees (Apoidea) and grasshoppers (Orthoptera). Furthermore, in the impact estimate, we considered both the overall species diversity (OSD) of each species group and the ecologically demanding species for amphibians, snails, spiders, carabid beetles, butterflies and grasshoppers (EDSs, stenotopic species, red-list species) for a total of 17 indicators.

2.2. Building the expert system: inventory of farmland crops and semi-natural habitats, farming activities, classification, characterisation and weighting

All typical farming activities such as insecticide use, manuring and mowing were listed in an inventory form for crops and SNHs of the Swiss farming landscape, namely arable crops, grassland and SNHs (e.g. extensively managed and low-input meadows, wildflower strips, hedges). The inventory was compiled with a view to covering as fully as possible the farmer's activities affecting biodiversity on his farm. Each farming activity was further

subdivided into management options describing how the farmer cultivated a crop or managed an SNH, e.g. type of insecticide or fertiliser used, time of application of the latter, or the mowing period (Appendix A, Table A.2). These options take account of the provisions of Swiss farming and environmental legislation. Since they are based on e.g. plant-protection products licensed in Switzerland, they should be adapted for use in other situations.

The detailed effects of the management options on each ISG were estimated based on information from the literature and expert knowledge. Most of the impacts of specific management options on indicator-species groups are known, and have been published in scientific papers. For example, the impact on butterfly species of the number of cuts made on a meadow (e.g. Erhardt and Thomas, 1989; Feber et al., 1996; Gerstmeier and Lang, 1996) as well as the impact of cultivation practices on carabid beetles (e.g. Clark et al., 1997; Hance, 2002; Holland, 2002) were described. Altogether, about 900 scientific publications and reports have been collected. We primarily looked for information focussing on the relationship between the ISGs and the farming practices investigated in Western Europe, and studies published from the 70s. In case of contradictory results, the information was evaluated and completed by experts before being entered in the rating system (Table 1). The impact of each management option on an ISG was rated on a relative basis, i.e. on a scale from 1 to 5, where 1 is the most damaging option and 5 the most favourable one (rating R , Table 1).

Since crops and SNHs of the agricultural landscape do not have the same suitability as habitats vis-à-vis specific ISGs, a coefficient ranging from 1 to 10 (C_{habitat}) was attributed to weight the rating of the management options for each specific ISG. Similarly, a second coefficient from 0 to 10 ($C_{\text{management}}$) quantified the relative importance for each ISG of farming activities occurring in crops and SNHs, e.g. grazing and mowing in grasslands, fertiliser and pesticide application for winter wheat. The final score S of a management option was the product of the rating of the management option R and the mean value of the two weighting coefficients C_{habitat} and $C_{\text{management}}$:

$$S = R \times C_f$$

where S = score, R = impact rating of a management option, C_f = final coefficient = $(C_{\text{management}} + C_{\text{habitat}})/2$.

Where management activities were repeated during the year (e.g. mowing), an annual average was calculated if the ISG was able to recover from one period to the next, or the most negative period was considered if damage was permanent. The final ISG score of a given crop or SNH was calculated as the mean of S 's over the management options occurring in that crop or SNH (see Appendix B, Table B.1 for an example of final S scores and final ISG scores calculated for the grassland flora in four grassland systems). Furthermore, ISG scores were aggregated to a biodiversity score by weighting each ISG score on the basis of trophic links between the ISGs and species richness of the ISG. The more important an ISG is as a basic food for other indicators and the more species-rich it is in the agricultural landscapes, the higher its weighting. Comparisons of management scenarios can then be

made at field level. Since ratings and coefficients were also defined for SNHs, ISG and biodiversity scores can also be calculated at farm level by aggregation of the scores obtained for single crops and SNHs (except for vegetable, fruit and grape crops).

2.3. Sensitivity analysis

We used a random sampling method (sensitivity analysis of parameters utilizing random sampling methods, Hamby, 1994) to identify the least and most influential farming activities of the inventory for each individual ISG (factors prioritization setting, Cariboni et al., 2007). Indeed, farming activities that do not significantly influence the final scores could be removed from real farm surveys in order to save time and effort in data collection. Blocks of farming activities of the inventory, e.g. fertilisation, pesticide application, mowing, were removed in turn prior to random sampling of possible ratings in the remaining blocks (1000 repetitions). For each repetition of randomly selected ratings in the remaining blocks, scores for each ISG were calculated with the expert system. A Wilcoxon test was then performed to check the statistical difference between scores obtained with all blocks of farming activities and scores calculated after the consecutive removal of blocks. Random sampling and tests were carried out with R (R Development Core Team, 2012).

2.4. Management scenario for two agricultural systems

Realistic scenarios for grassland and winter wheat management systems in the Swiss lowlands were defined in order to illustrate the use of the method and discuss the results of impact calculation on ISGs (Table 2, Nemecek et al., 2005). All typical farming activities for grassland and winter wheat fields, such as fertilisation, mowing, and insecticide and fungicide applications were specified with options, e.g. type of fertiliser and mowing period, type of insecticide and fungicide and application period. Scenarios addressed a large intensity gradient of grassland systems, ranging from one utilisation and no fertilisation (2.7 t DM/ha and year) to five utilisations and fertiliser applications (11 t DM/ha and year). Similarly, various cropping systems were considered for winter wheat along a gradient of production intensity (3.5–5.8 t DM/ha and year).

2.5. Validation of grassland system scores with plant and grasshopper data collected in the field

Two of the ISGs, i.e. vascular plants and grasshoppers, were recorded in grasslands for comparison with scores calculated using the expert system. In 2008, 10 grassland-dominated farms were chosen along a large management intensity gradient at the southern margins of the Swiss Jura Mountains (Canton of Aargau) at altitudes of between 350 and 750 m a.s.l. The management intensity gradient was defined by the livestock unit (LU) per ha utilised agricultural area (UAA) (2.2 LU/ha on average, with a range of 0.09–6.08 LU/ha) and the percentage of ecological compensation area (40.4% on average, with a range of 8–92%). Vascular plants and

Table 1
Rating R of the impact of the management option on the selected indicator-species groups (ISGs).

- | | |
|---|---|
| 1 | The option leads to a severe impoverishment of species diversity within the species group considered, and renders impossible the occurrence of stenotopic species and red-list species. |
| 2 | The option leads to a slight impoverishment of species diversity within the species group considered, and renders impossible the occurrence of stenotopic species and red-list species. |
| 3 | The option has no direct effect on the species group considered. |
| 4 | The option leads to a slight increase in species diversity within the species group considered, and makes possible the occurrence of stenotopic species and red-list species. |
| 5 | The option promotes species diversity within the species group considered, and makes possible the occurrence of stenotopic species and red-list species. |

Table 2

Management and production characteristics of grassland and winter wheat systems used to test the method of impact calculation on ISGs.

Systems		Management and production characteristics
Grassland (hay production)		
A	Intensive grassland	5 cuts/year, fertilised with slurry; 11 t DM/ha
B	Fairly intensive grassland	4 cuts/year, fertilised with slurry; 9 t DM/ha
C	Low-intensity grassland	3 cuts/year, fertilised with solid manure; 5.6 t DM/ha
D	Extensive grassland	1 cut/year; no fertilisation; 2.7 t DM/ha
Winter wheat systems		
E	Conventional production	5.8 t DM/ha
F	Integrated production–intensive	5.5 t DM/ha
G	Integrated production–extensive	4.5 t DM/ha
H	Organic production	3.5 t DM/ha

grasshoppers were recorded in the field on each grassland plot of 10 ($n = 198$ plots) and six ($n = 77$ plots) farms, respectively.

All plant species present on a 25 m² circle representative of the plot were recorded in the field. In the case of a heterogeneous plot presenting a mosaic of patches of different vegetation types, the plant list was the sum of plant species found in each patch. Grasshopper species were recorded visually and acoustically on sunny days with little or no wind during an hour-long walk across the plot. Species richness and high-nature-value scores (for grasshoppers only, derived from the Swiss Red List according to Monnerat et al., 2007) were extracted from the field data. A weighted average was taken to calculate the overall plant-species richness of heterogeneous plots, bearing in mind the percentage of area covered by each vegetation patch.

Detailed data on agricultural practices vis-à-vis fertilisation, mowing, grazing and weed or mice control that took place in 2008 on each plot were directly obtained from the farmers via questionnaires. Data were then entered into the expert system to derive scores for each individual plot as well as for the entire farm. Expert system outputs, i.e. scores for the overall species diversity (OSD) of plants and grasshoppers, as well as ecologically demanding species (EDSs, grasshoppers only) calculated on the basis of the agricultural practices, were compared to the species richness and high nature values of plants and grasshoppers recorded in the field. Correlations were tested with the Spearman rank correlation coefficient. To investigate possible model simplification, scores based on single groups of farming practices, i.e. fertilisation, mowing, grazing and pesticide application, were calculated with the expert system, and correlated each separately to the observed species richness (only for plots where the four groups of farming practices took place). In case of multiple significant correlations, model selection with linear statistical modelling and AIC (Akaike information criterion, Burnham and Anderson, 2002) was then used to reveal which scores originating from which group(s) of farming practices were the most influencing. All analyses were performed with the statistical program R (R Development Core Team, 2012).

3. Results

3.1. Sensitivity analysis

Unsurprisingly, the sensitivity analysis revealed that the main farming practices causing disturbance, fertilization, plant protection, soil preparation and sowing, cutting and harvesting, grazing, and watering significantly influenced scores, largely irrespective of crop and SNH types (Appendix B, Table B.2). With crops, fertilisation and plant protection measures had the greatest effect on scores of most of the ISGs. For example, scores for 9 out of 11 ISGs differed significantly when plant protection measures were deactivated for the calculation of scores in summer cereals. The two ISGs not affected were amphibians and spiders, but for

different reasons. In the case of amphibians, a lack of information meant that many plant protection measures could not be rated, with the result that this farming practice had no real influence on the scores in the model. For spiders, scores attributed to the impact of plant protection measures were more similar to other farming practices than they were for the other ISGs. When plant protection measures were deactivated, final scores which were means of scores over the management options were not significantly different.

Similarly, scores of 14, 12 and 9 out of 15 ISGs were significantly influenced by grazing in unproductive, moderately productive and highly productive grasslands, respectively. For six ISGs, including butterflies, grazing did not influence the final score more than other farming practices did, since all of the latter were highly important.

Table 3

Biodiversity scores for grassland and winter wheat systems calculated with the expert system. Scores of grassland system (A) and winter wheat system (F) are set as reference scores. Scores with the same format are considered similar to the reference (95% < score < 104%); underlined scores are considered better than the reference (105% < score < 114%); double-underlined and in bold scores are considered much better than the reference (score > 115%). Depending on ISG, the theoretical minimum score in SNHs is 1 and the maximum is 40–50. 'No score' means a lack of significance for the system in question. Option details and scores for the four grassland systems are given in Appendix B, Table B.1.

Production systems	Biodiversity scores							
	Grassland intensity				Winter wheat intensity			
	A	B	C	D	E	F	G	H
Overall species diversity (OSD)								
Aggregated ^a	6.2	6.4	13.8	21.3	7.7	7.5	8.4	8.7
Grassland flora	3.8	4.0	15.4	22.1				
Crop flora					15.2	15.1	16.0	17.3
Birds	6.4	6.7	13.8	22.0	5.3	5.0	6.2	6.4
Mammals	7.3	7.3	11.1	11.1	4.6	4.6	4.6	4.6
Amphibians	2.1	2.1	5.2	9.5	1.7	1.7	1.8	1.8
Snails	5.4	5.6	5.8	11.3	2.2	2.2	2.2	2.2
Spiders	9.1	9.3	15.8	22.4	8.2	8.0	10.5	10.7
Carabid beetles	7.0	7.4	13.6	21.0	10.9	10.6	11.7	11.9
Butterflies	6.8	7.0	20.0	36.0				
Wild bees	7.4	7.6	18.6	23.0	5.2	4.9	5.0	4.8
Grasshoppers	6.9	6.9	19.4	33.1				
Ecologically demanding species (EDSs)								
Amphibians	0.8	0.8	2.9	4.8	1.5	1.4	1.6	1.6
Spiders	8.9	9.0	15.3	21.6	8.0	7.8	10.3	10.5
Carabid beetles	7.0	7.3	13.4	20.6	10.6	10.1	11.2	11.3
Butterflies	6.7	6.8	19.4	36.0				
Grasshoppers	6.8	6.8	19.3	32.9				

^a ISG scores are aggregated bearing in mind rules of trophic relationships between indicator species groups.

3.2. Impact of two agricultural systems on indicator species groups

The comparative results of grassland and winter wheat systems suggested that these crops were on average less suitable for most of the ISGs (Table 3). The transition from conventional and intensive integrated winter wheat systems (production systems E and F) to extensive (integrated) and organic production (production systems G and H) did not reveal the spectacular increase in scores occurring in the transition from intensive and fairly intensive (A and B) to low-intensity and extensive grassland systems (C and D). Despite this, conventional and integrated winter wheat systems (E and F) exhibited slightly higher aggregated biodiversity scores than the most intensively managed grasslands (A and B), a difference due mainly to the higher scores achieved by the crop flora than the grassland flora, and by the carabid beetles as shown in detailed ISG results. The highest scores of 36.0 (D) and 17.3 (H) were calculated for butterflies in extensive grassland and crop flora in winter wheat, respectively, whilst the lowest of 0.8 (A and B) and 1.4 (F) applied to amphibians in intensively managed grassland and winter wheat, respectively. For purposes of rough comparison, the aggregated biodiversity score of a hedgerow (result not shown), as a typical SNH of the agricultural landscape, is about 21, and varies between 11 and 38, depending on ISG.

Calculated for the range of grassland types, scores for aggregated biodiversity, OSD of most of the ISGs, and for the EDS unequivocally increased with decreasing management intensity (production systems A–D) (Table 3). Scores for EDS were slightly lower than those of OSD. An obvious inflection point occurred between 4 and 3 cuts/year (fairly intensive and low-intensity grasslands, respectively) and with a change in fertiliser type. In fact, aggregated biodiversity scores increased by 0.2 from intensive to fairly intensive, and by 7.4 from fairly intensive to low-intensity management. By contrast, scores increased by an additional 7.5 from low-intensity to extensive grasslands. However, ISG did not react all the same. Snails were an exception to the pattern, the largest difference occurring between low-intensity grassland and extensive grassland (93.9% increase). Here, the absence of fertilisation was more important for snails than type of fertiliser. Extensive grasslands obtained higher biodiversity scores than low-intensity grasslands, except for mammals, which do not show any difference between these two types. The largest difference in percentage occurred between fairly intensive and low-intensity grasslands for the aquatic life phase of the amphibians, but at a very low score level (aquatic life phase, 0.8–2.9, 262.5%). The highest scores were obtained for butterflies in extensive grasslands (36.0 for overall diversity and ecologically demanding species), followed by grasshoppers and wild bees.

As for winter wheat systems, organic production achieved the highest aggregated biodiversity and ISG scores. Aggregated biodiversity scores increased gradually and incrementally from intensive integrated production (reference system) to organic production, i.e. F–E, 0.2 (2.7%), E–G, 0.7 (9.1%), G–H, 0.3 (3.6%). Interestingly, spiders and birds exhibited the highest increase in scores from conventional (E) to extensive integrated production (G), with 2.3 (28%) and 0.9 (17%), respectively, and 2.3 (28.8%) for ecologically demanding spider species. The lowest scores were calculated for amphibians, snails and mammals, for all three of which a change in production system brought about only a minor shift in scores. By contrast, conventional production achieved a slightly higher score for wild bees at a relatively low level (5.2). No scores were calculated for grassland flora, butterflies and grasshoppers, since crop fields are of negligible or no importance as a habitat for these ISGs.

3.3. Validation of grassland system scores with plant and grasshopper data collected in the field

A total of 294 plant and 17 grasshopper species were recorded, with an average of 29.4 plant and 5.7 grasshopper species per plot. OSD scores derived from the expert system for plants varied from 8.9 to 19.3, with an average score of 12.1 per plot corresponding to production systems B–D of Section 3.2. OSD scores for grasshoppers ranged from 10.8 to 29.8, with an average score of 18.9 per plot corresponding to production systems B–C, whilst EDS scores varied from 10 to 27.3, with an average score of 17.7.

At plot scale, plant OSD scores were highly correlated with the number of plant species found in the field (Fig. 1, $n=198$, Spearman's rank correlation $r_s=0.58$, $P<0.001$), as were grasshopper OSD scores with the number of grasshopper species (Fig. 1, $n=77$, $r_s=0.39$, $P<0.001$). Grasshopper EDS scores also correlated significantly and positively with the high nature values of grasshopper species ($n=77$, $r_s=0.23$, $P<0.05$). In addition, scores calculated for the four groups of farming practices separately, i.e. fertilisation, mowing, grazing and pesticide application, showed significant correlations (except scores based on grazing) with the observed plant ($0.31 < r_s < 0.59$, $P < 0.05$) and grasshopper species richness ($0.24 < r_s < 0.39$, $P < 0.05$). Linear models and model selection based on AIC with the four groups of scores as individual explanatory variables, revealed that the best and most parsimonious model was the one with scores originating from the fertilisation and pesticide application (additive model, no interaction) to explain the observed plant species richness ($F_{\text{statistic}}=61.02$, $P < 0.05$), and from the fertilisation only to explain the observed species richness of grasshoppers ($F_{\text{statistic}}=7.04$, $P < 0.05$).

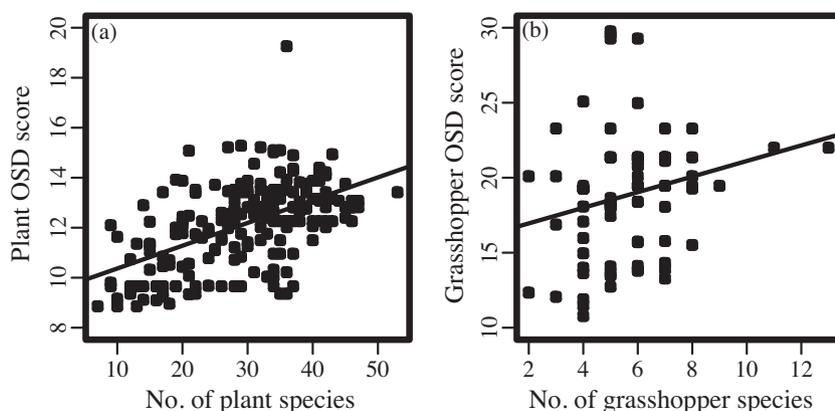


Fig. 1. Number of species versus expert system scores. Correlations between scores obtained with the expert system according to agricultural practices used, and the number of species recorded in the field for (a) plants and (b) grasshoppers.

4. Discussion

Expert system results matched well with ecological interpretations (plausibility, production system comparison and field survey), whilst sensitivity analysis confirmed the main activities influencing the scores. Because farming activities taken as a whole always affected more than one ISG, we recommend that all activities be retained in order to permit comprehensive and meaningful comparisons between agricultural production systems. In particular situations, however, a reduced recording of farming activities may provide the necessary information (see below paragraph on data collected for plants and grasshoppers in fields). In addition, such a system should continuously be improved by updating scores along with new results published. Indeed, the rating model depends on published experimental and observational studies as well as on expert knowledge. It might be that factors which have a hidden impact on species have systematically been discarded by research, or were not properly investigated. This cannot be detected by sensitivity analyses.

The results of the expert system calculation of ISGs and the aggregated biodiversity scores for two production systems suggest that biodiversity is on average less impacted by grassland than by winter wheat systems. This can be explained by a wider-ranging disturbance level usually occurring in crop fields than in grasslands. This has been empirically observed in investigations of arthropods and plants (e.g. Schmidt and Tschardt, 2005; Weibull and Östman, 2003), as well as amphibians (e.g. Wells, 2007), although effects largely depend on management intensity. Indeed, the difference between grassland and winter wheat was greater in less productive systems, i.e. in extensive and low-intensity grassland as opposed to extensive integrated or organic production of winter wheat. This is because a crop field remains a monoculture with low micro-habitat and niche diversity, even in extensively managed systems. By contrast, extensively managed grasslands usually harbour great micro-habitat and niche diversity by providing species-rich vegetation (e.g. Klimek et al., 2007; McLaughlin and Mineau, 1995). The spectacular scores obtained by the majority of the ISGs in the extensive grassland system highlighted the importance of this form of management for biodiversity. The scores decreased distinctly in two steps, first from extensive to low-intensity grassland, then from low-intensity to fairly intensive and intensive grassland, thereby demonstrating that impacts occurred due to the increasing number of cuts (1–3 cuts/year and 3–5 cuts/year, respectively), which in turn directly affected habitat and fertilisation type. The high scores for butterflies, grasshoppers and wild bees in extensively managed grassland were due primarily to the high habitat coefficients attributed to grassland habitats, reflecting the latter's importance in the agricultural landscape as a potential habitat for all three of these ISGs. Detailed analysis of the results also showed that increasing management intensity as well as production level – i.e. from low-intensity to fairly intensive grasslands – produces a dramatic 116% decrease in the aggregated biodiversity score.

For the winter wheat systems, organic production obtained the highest scores for the aggregated biodiversity and ISG scores, still not reaching the higher scores of extensively managed grassland. This is in line with the management techniques that are normally used in this system and their impact on ISGs, i.e. no application of chemical-synthetic pesticides and lower fertilisation rate (e.g. Hole et al., 2005). Intensive integrated production had a greater negative impact on spiders and birds in particular than did extensive integrated production, owing to the former's use of non-selective pesticides and the greater frequency of disturbances it entails. This emphasizes the need of a multiple ISG approach because high variability was revealed in winter wheat systems by birds and

spiders while butterflies, grasshoppers and wild bees were more sensitive to grassland management.

For both plants and grasshoppers, a comparison of the scores obtained via the expert system with data collected in the field has shown that knowledge of current agricultural practices is sufficient to estimate the number of species in the grasslands studied, and to draw inferences on the impact of such practices. Results confirmed outputs of the sensitivity analysis which highlighted the importance of fertilization, cutting, grazing and pesticide application on plants and grasshoppers in grassland. Model selection showed that scores solely based on fertilization and pesticide application in case of plants, and fertilization alone in case of grasshoppers, can explain the observed species richness. However, as soon as several ISGs are included in the impact assessment, which is the goal of such an expert system, the survey of a large set of agricultural practices is unavoidable because each ISG will likely respond differently. Despite nature-friendly management, certain sites can bias results with a relatively low number of species. For instance, a litter meadow with 36 plant species managed according to the special rules of the Swiss agri-environmental scheme obtained a very high score for plants (19.3) due to nature-friendly management, whilst other fields with a similar number of species achieved a very low score using the expert system, owing to their intensive management (three fields with score <10 and more than 34 species). This can occur in specific fields where environmental conditions are favourable for plant species even under intensive management, or when management events do not yet show an effect on vegetation (e.g. conversion from conventional to organic farming, application of agri-environmental measures). For the same reasons, a number of fields managed according to special nature-friendly rules imposed by the Swiss agri-environmental scheme for grasslands (low-input, restrictions on mowing) did not harbour high numbers of grasshopper species, despite having high scores (four fields with scores >28 and less than 7 species). This also indicates that it is not just the number of species observed in the field that should be considered for comparison with the expert system scores, but also the species assemblages, as well as e.g. rare species.

There are great advantages to using an expert system based on the detailed impact of farming operations on several indicator species groups. Firstly, different ISGs do react differently to various management options and farming systems. The use of several indicators enables us to better estimate the impact on biodiversity as a whole, given that no single indicator can be derived that surrogates for all other organisms in terms of its reaction to farming operations (Büchs, 2003). This method can also reveal the potential conflicts arising through the use of nature-friendly measures unable to support all of the species groups together, and may therefore help with decision-making by weighting the species groups according e.g. to regional goals. Secondly, the bottom-up approach permits the biodiversity scores for particular management options to design recommendations at field level. Fields scores can then be aggregated to the next, i.e. farm, level. At this level, we acknowledge that the proportion of semi-natural habitats, ecological infrastructures (or ecological compensation areas, ECA) is the main driver for biodiversity, generally (e.g. Tschardt et al., 2005). This is why semi-natural habitats (ECA) are included in the expert system. However, estimating impacts at the finest level allows to take into account more subtle effects that makes possible to differentiate between fields, crop rotations, farming systems, and farms which show the same amount of ECA. Furthermore, recommendations can also be more accurately proposed if not only important drivers, e.g. the livestock unit per ha, are considered but further characteristics like the period of grazing and the type of animals which are both important factors impacting the ISGs. Farm scores can then be aggregated to the

regional level. In addition, crop rotations can be evaluated by aggregating crop scores of crops occurring during the rotation. The aggregation procedure can be used to investigate the impact of land-use scenarios on biodiversity at farm or regional level, exploring, for instance, the potential benefit in terms of biodiversity of intensively managed fields with a resultant high production rate in a portion of the farmland, coupled with more space for fields managed in a nature-friendly manner, as opposed to the low-input management of all of the farmland. These issues were recently discussed in Hodgson et al. (2010). The expert system presented here is an initial tool for anticipating the impact of land use and farming changes on biodiversity. Although the method will not completely replace the accurate in situ observation of biodiversity for purposes of evaluating the actual impact, it may help with the design of new studies on the specific impacts of farming activities on particular species groups. In addition, the method can assist stakeholders, land managers and decision-makers in prioritising specific measures for preserving biodiversity in farming landscapes according to the model outputs.

The expert system can easily be integrated into an agricultural LCA methodology with an area related functional unit as an additional impact category alongside the commonly evaluated impacts such as toxicity and global warming (e.g. SALCA methodologies, Nemecek et al., 2005). Based on relatively rough estimations of the impacts of individual farming practices on biodiversity indicators, the expert system proved to be robust enough and sufficiently sensitive to be implemented in the framework of LCA methodologies. The application presented here focuses on the scoring of individual agricultural fields, and can potentially be scaled up to farms or crop rotations, as farms can be aggregated to regions. Although no assessment of the impact on biodiversity at a larger scale (biomes or continents) can be made, the expert system could be extended further in two steps. For application to Central and Western Europe, validation is needed. For application beyond Europe, scores from local literature and expert knowledge should be re-evaluated, since they may differ owing to different species assemblages.

Unlike other methods that aim to integrate biodiversity into LCAs, the proposed expert system does not refer to an initial or reference biodiversity condition, but instead estimates the impacts of various farming practices in a relative manner. The disadvantage with this method is that it cannot give an absolute value for species loss. The advantage of this approach is that no definition of an initial stage of the biodiversity condition is needed which may be challenging or controversial, if not downright impossible under certain circumstances (de Baan et al., 2013). The method can then be applied in a range of situations that can be compared to one another in terms of impact.

5. Conclusion

Although limited to agriculture, the expert system represents an important step towards the inclusion of biodiversity in LCAs. Using this expert system allows us to identify the impacts of the most important agricultural practices and choices of farmers on biodiversity. The impacts of agricultural practices on several indicator species groups of the above-ground habitats occurring in grassland and crop systems can then be compared, and recommendations made accordingly.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.ecoind.2014.06.030>.

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