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Biodiversity assessment in LCA: a validation at field and farm scale in eight European regions

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Abstract

Purpose: Inclusion of biodiversity as an indicator in the land use impact pathway of Life Cycle Assessment (LCA) is essential to assess the effects of human activities on the environment. Numerous models have been applied, but validations that use actual data, collected in the field, are scarce.

Methods: The expert system SALCA-BD (Swiss Agricultural LCA – Biodiversity), assigns coefficients for land use class suitability and impact of agricultural practices on species diversity at field and farm scale. We used data on land use classes and agricultural practices from 132 farms located in eight European regions to complete the life cycle inventory. SALCA-BD species diversity scores were calculated for individual fields, aggregated to the farm scale and compared to field records of arable crop flora, grassland flora, spiders and wild bees.

Results: Overall, species diversity scores from SALCA-BD were positively related to the observed species richness from field survey data. The extent of the relationship diminished from arable crop flora and grassland flora to spiders and to wild bees, and from field to farm scale.

Conclusions: Validation of a LCA biodiversity assessment tool with data from field surveys revealed the benefit of considering multiple aspects of biodiversity. The appropriate scale for species diversity assessment (as a proxy for biodiversity) is the respective species habitat. Extension of scale increases uncertainty, which should be addressed by developing characterization factors for as detailed a land use classification as possible.

Keywords

Agriculture; Biodiversity indicators; Farmland biodiversity; Life Cycle Assessment; SALCA; Species diversity

1 Introduction

Terrestrial biodiversity has been affected by agricultural land use, and its decline in recent decades leaves no doubt as to the urgent need for reliable information on its state and changes, not least because human well-being is closely linked to biodiversity and to the goods and services that ecosystems provide (Robinson and Sutherland 2002; MEA 2005; Perrings 2014; UN 2012). Besides its intrinsic value, biodiversity is part of the essential natural resources to agricultural production (Balvanera et al. 2006). The necessity of incorporating impacts on biodiversity in LCA methodologies has long been recognized (UNEP/SETAC Life Cycle Initiative; Jolliet et al. 2004; Milà i Canals et al. 2007), and the state of the art has been summarized in reviews (Curran et al. 2011; Koellner and Geyer 2013;

Lenzen et al. 2007). However, biodiversity assessment is a crucial issue but hardly tangible due to its complexity (Souza et al. 2015).

Dating back to the 1990s, several efforts have been made to include biodiversity in LCA of land use impacts, including attempts to quantify how uncertainties in the relationship between species and area may influence LCA outcomes (Lindeijer 2000; De Schryver et al. 2010). Nevertheless, there is no agreement yet on one generally successful concept that can include the multiple aspects of biodiversity, although substantial progress has been made and was recently published in the framework of the UNEP/SETAC Life Cycle Initiative (Curran et al. 2016), and recommendations were released such as the necessity of validating LCA outcomes with data from field survey (Teixeira et al. 2016).

Most LCA approaches distinguish between the impacts of land transformation and those of land occupation. The concept is based on the assumption that land use can be described by a number of discrete land use classes. Land transformation involves changing the land cover of a certain area from one land use class to another in a permanent way, such as conversion of native forest to arable land, transforming grassland to arable land, or replacing agriculture with urban land use. Land occupation impacts are the effects on land quality of ongoing activities in an area belonging to a specific land use class (Milà i Canals et al. 2007; Schmidt 2008; Souza et al. 2015). Koellner et al. (2013) have suggested a globally applicable classification of distinct land types, specifically for the purposes of LCA. This allows the assessment of land transformation and occupation effects at a coarse scale and covering all areas (De Baan et al. 2013). Due to underlying simplifications, however, this system may be unable to capture specific determinants of biodiversity in specific regional circumstances. Not surprisingly, modelling state and changes of real biodiversity remains challenging because of the complexity and dynamics of biodiversity in itself, as well as data limitations and conceptual issues (Curran et al. 2011). In this context, the following two aspects need particular attention (Chaudhary et al 2015; De Baan et al 2015; Koellner et al. 2013; Souza et al 2015):

- The need to clearly specify which aspect of biodiversity is under study, e.g. nature conservation or functional issues; diversity of genes, species or ecosystems; and, in the case of using surrogates, how representative these are for the aspect in focus. As biodiversity includes the entire variability among living organisms and ecological complexes, it encompasses so many facets, aspects and dimensions that it cannot be measured as a whole. Therefore, indicators are used to assess the state of and changes in biodiversity. Single indicators can provide insight only into certain aspects of biodiversity. A more comprehensive assessment is achieved by using a set of complementary indicators that represent e.g.

different ecological niches, trophic interactions, mobility, responses to agricultural practices and/or ecosystem services (Büchs 2003; Duelli and Obrist 2003).

- The spatial scale, the classification of land cover and land use and the up-scaling from local to global scales or vice versa, which has considerable limits because regional peculiarities and landscape composition are crucial factors. The field scale is the most detailed approach, since it represents a management unit in agriculture. It allows for the evaluation of direct relations between species diversity and human activities for individual land use classes. By accounting for the proportional area of the different land use classes, results can then be up-scaled to the farm scale or larger areas. In the case of agricultural landscapes, the individual farms are of crucial importance because major decisions for biodiversity are taken at this scale.

A critical step in the development of models of the effects of land use on biodiversity is to validate the models using empirical data (Ciroth and Becker 2006). Our objective here is to validate an expert system (SALCA-BD for Swiss Agricultural LCA – Biodiversity; Jeanneret et al. 2014), which has been applied in several agricultural case studies (Nemecek et al. 2008, 2011a, 2011b, 2015). The expert system SALCA-BD assesses the habitat suitability and beneficial or detrimental effects of agricultural practices (land occupation impacts) from land use and management information at the finest scale, i.e. the field, on terrestrial species diversity represented by a set of indicator species groups (ISGs). To validate SALCA-BD for four of its ISGs, namely arable crop flora, grassland flora, spiders and wild bees, we used species data of ground surveys of a range of contrasting farming conditions across Europe from a European research project on biodiversity indicators in farmland (Herzog et al 2012).

2 Methods

2.1 The expert system

SALCA-BD was developed to assess land occupation and land management impacts on biodiversity at the midpoint level of the impact pathway. It relies on published experimental and observational data as well as expert knowledge. The method is explained in detail in Jeanneret et al. (2014) and is validated here with species data of ground surveys.

The SALCA-BD expert system is embedded in the SALCA method, i.e. the Swiss Agricultural LCA, which performs a comprehensive assessment for a large variety of agricultural systems (Gaillard and Nemecek 2009). Life cycle impact assessment within the SALCA framework is performed for a comprehensive set of impact categories at midpoint level that are relevant for agricultural systems. No damage modelling to the endpoints is carried out. Biodiversity is therefore analyzed as a midpoint category, in contrast to some other impact modelling frameworks (e.g. Souza et al. 2015; Curran et al. 2016), where biodiversity impacts are modelled to their endpoint.

Land area is the functional unit of SALCA-BD. Using a bottom-up approach, the expert system relies on information about land use class and agricultural practices at the field scale. Further, impacts across multiple fields of different classes are aggregated to impacts at the farm and regional scale. In SALCA-BD, eleven indicator species groups (ISGs) were selected with criteria taking into account the relationship to the agricultural activity as well as general criteria such as ISG distribution, habitats, and level in the food chain. Below ground biodiversity is not considered in the expert system. SALCA-BD provides dimensionless biodiversity scores based on a life cycle inventory and considers, first, the suitability of land use classes such as arable crops, grasslands and semi-natural habitats for the ISGs. A specific suitability coefficient is assigned to each land use class per ISG ranging from 0 to 10 (see a list of land use classes in Appendix A, Table S1 in ESM, Electronic supplementary material). For example, a coefficient of 0 is assigned to the land use class "wheat field" for the ISG "grassland flora" because wheat is no habitat for the grassland flora. Second, agricultural practices in the respective land use class are listed in the life cycle inventory, e.g. soil cultivation, sowing and planting, fertilization, crop protection, cutting/grazing and harvesting. Again, coefficients from 0 to 10 are assigned that reflect the sensitivity of the ISGs to the various agricultural practices. For instance, butterflies are extremely sensitive to the cutting regime in meadows and got therefore a coefficient of 10 for this practice. Furthermore, each detailed option of each agricultural practice such as the date of e.g. cutting, the quantity of e.g. fertilizer, the type of e.g. crop protection, and the technology of e.g. soil preparation is assessed regarding its relative impact on the ISGs on a scale from 1 to 5 (impact rating). The assessment procedure results finally in an overall species diversity score (OSD score) for each ISG per land use class and practice, which range then from 0 to 50 (mean land use class and practice coefficient times impact rating). An OSD score of 0 means that the land use class is no habitat for the considered ISG. An OSD score of 50 means that the land use class and the practice is of primary importance for the considered ISG, and that the impact of the practice is positive (rating is 5). For instance, ruderal semi-natural habitats are particularly favorable for wild bees and get an OSD score of 50. Additionally, the OSD scores of the individual ISGs are weighted according to the total species richness of the ISG and its position in the food web to result in a combined score for aggregated biodiversity per land use class. All individual ISG scores as well as the aggregated biodiversity score per land use class can be aggregated further to larger spatial scales such as farm or region.

2.2 Data sources

Species and land use data of eight European regions were collected in 2010 in the EU-FP7 project BioBio, which developed biodiversity indicators for farmland monitoring (Table 1; Herzog et al. 2012). The data comprise detailed maps of 132 farms with all fields, i.e. arable crops and grasslands and semi-natural habitats such as hedgerows, groves or wildflower strips (Dennis et al. 2012). The land use classes of the BioBio project were translated to the land use classes of the life cycle inventory of SALCA-BD. Information about agricultural practices per field were collected through interviews with the farmers, following a standardized questionnaire, and transferred to the life cycle inventory.

Species data were collected following a stratified sampling design aiming at comprehensive species lists at farm scale (for each land use class per farm, one field was randomly selected). In each selected field, vascular plants (arable crop flora and grassland flora), spiders and wild bees were sampled according to standardized protocols (Dennis et al. 2012). During the BioBio project process, the four species groups were selected following a scientific knowledge assessment, survey practicability in a range of farming systems, and stakeholder consultation. They represent contrasting resource requirements, trophic levels and mobility (Jeanneret et al. 2012a). We used the observed species richness (i.e. number of species) as a proxy for biodiversity, as species richness was generally correlated with other species diversity measures (Jeanneret et al. 2012b). The observed number of species was recorded for all four ISGs in each selected field (see Table S1 in ESM for the average number of species per ISG, land use class and region). At the farm scale, the observed total number of species per ISG that was found across the land use classes of the farm was recorded. In the ecological context, this represents the observed gamma diversity. Gamma diversity combines the average diversity within the community of a land use class (alpha diversity) and the diversity among the communities (beta diversity; Veech et al. 2002). We deem gamma diversity to be of particular interest for stakeholders as an easily understood indicator.

2.3 Data analysis

2.3.1 Grouping of data

Whilst management information was complete for agricultural fields, it had not been recorded for semi-natural land use classes (mostly linear land use classes such as hedgerows, grassy strips, etc. without production purpose). For semi-natural land use classes, therefore, OSD scores are solely based on the suitability coefficient of the respective land use class. Hence, two data sets were analysed separately:

- Reduced data set (667 fields in 131 farms): exclusively fields with available information about agricultural practices, analyses at field scale and at farm scale (farm scale A).
- Full data set (1263 fields in 132 farms): all fields with and without available information about agricultural practices, including semi-natural land use classes; analyses at farm scale only (farm scale B).

The reduced data set allowed investigations at the highest level of detail possible at field scale and the validation of the aggregation procedure at farm scale A. The full data set provided insight in the effects of semi-natural land use classes at farm scale.

2.3.2 Statistics

The four ISGs, arable crop flora, grassland flora, spiders and wild bees, were analysed individually. To investigate whether the observed species richness of each ISG was related to the OSD scores calculated by SALCA-BD, we used generalized linear mixed-effects models (see Appendix B in ESM for the formulas, Zuur et al. 2013). First, we assumed a Poisson distribution for our response variable, i.e. the observed species richness, which consists of count data. When the modelling results indicated that the variance was larger than the mean (overdispersion), we applied the more appropriate negative binomial distribution. Land use class and region were included as two categorical variables in the random part of the model. All possible combinations of varying intercepts and slopes for the random effects were calculated. For each ISG the best model was selected based on the Akaike information criterion (AIC) that is a combination of model fit as measured by the log-likelihood value, and model complexity as measured by the number of parameters (Akaike 1973). From the corresponding best models, we evaluated how well species richness was represented by the OSD scores (fixed effects) based on the direction and significance of the estimated coefficients (slope) and the meaning of including or excluding random effects. In a second analysis, we performed generalized linear models with negative binomial distribution for each ISG per region separately (see Appendix B in ESM for the formulas).

3 Results

Overall, we found positive relations between observed species richness and calculated overall species diversity scores (OSD scores) for the four indicator species groups (ISGs) (Table 2, Fig. 1). The relations were stronger for arable crop flora and grassland flora than for spiders and wild bees, and they decreased in strength from field scale to farm scale A and then to farm scale B. For each region, considered separately (Table 3), significant positive relations were found for arable crop flora and grassland flora in the majority of the regions, whereas this was the case in half of them for spiders and in one quarter for bees. All significant relationships were positive except the observed species richness of wild bees and the overall species diversity scores in the Bulgarian (BG) region.

3.1 Arable crop flora

Observed species richness and OSD scores of arable crop flora were low in maize fields but high in cereal fields (Fig. 1). At field scale, this was reflected by the inclusion of varying intercepts for land use classes in the best model (Tab. 2). In addition, this model allowed varying slopes but not varying intercepts for region, which indicates a stronger or weaker increase in the observed species richness with higher OSD scores depending on the region but similar levels in observed species richness across regions. At farm scale A, the positive relation relied mainly on the farms in the German (DE) region, where a broad variety of cropland land use classes occurred (Fig. 1 and Table 3). Varying slopes for regions were included in the best model. At farm scale B, semi-natural land use classes added considerable numbers of species to the total farm species richness observed. OSD scores hardly increased, however, because such land use classes normally cover only small areas. Total farm species richness was high in the French (FR) region compared to the other regions. One farm from the French region that strengthened the positive result, was a farm in which the only land use class containing arable crop flora was the semi-natural land use class 'wild flower strip'. The best model included varying intercepts for regions.

3.2 Grassland flora

For grassland flora, observed species richness and OSD scores were clearly higher in permanent grassland (meadows, pastures and forest pastures) than in leys (Fig. 1). Therefore, at field scale, varying intercepts for land use classes were included in the best model (Tab. 2). In addition, the best model let the intercepts and slopes for regions vary. We found distinct positive relationships in regions where both leys and permanent grasslands existed (the German (DE), French (FR) and the Hungarian (HU) region), or where the majority of permanent grasslands were managed as meadows, i.e. exclusively cut or cut and grazed (the Swiss (CH) and the Norwegian (NO) region, Tables 3 and S2 in ESM). No distinct relationships could be detected in regions where leys were the only land use class for grassland flora (the Austrian (AU) region) or where the majority of permanent grasslands were managed as pastures, i.e. exclusively grazed (the Bulgarian (BG) and the Welsh (GB) region). At farm scale A, the variability between regions was expressed in varying intercepts for regions (Fig. 1). At farm scale B, the positive relation between total farm species richness and OSD scores was not significant.

3.3 Spiders

Observed spider species richness was significantly but weakly positively related to OSD scores at field scale (Fig. 1, Tab. 2). The best model included varying intercepts for land use classes and regions, taking into account lower species richness in cropland than in grassland and differences between regions. No varying slopes were included in the best model. At farm scale A, the overall positive relationship was not significant. In the Austrian (AT), German (DE), French (FR) and Hungarian (HR) region, spider species richness clearly increased with higher OSD scores, whereas there was no distinct pattern in grassland dominated regions (Fig. 1 and Table 3). In the French (FR) region, total farm species richness was much higher than would be expected from the calculated OSD scores. The average observed number of spider species increased by around twenty species at farm scale B, revealing the importance of including semi-natural land use classes but the relationship with OSD scores was not significant.

3.4 Wild bees

OSD scores for bee species richness at field scale formed two groups (Fig. 1). The lower group included arable land use classes. The higher group included grassland land use classes. Observed bee species richness followed this trend (Tab. 2). The strongest positive relation was found in the French (FR) region (Table 3). Overall, in many fields only few or even no bee species were observed. The best model included varying intercepts for land use classes and varying intercepts and slopes for regions, the same as the best model for grassland flora. At farm scales A and B, bee species richness was not significantly related to OSD scores across regions but trends were positive in cropland regions while there were no relationships, or in one case a negative, in grassland-dominated regions (Fig. 1).

4 Discussion

Our study detected a significant positive relationship between the biodiversity indicator, i.e. overall species diversity scores (OSD scores) calculated with the SALCA-BD expert system and empirical data of species richness for each tested indicator species group (ISG) at field scale. Since large field surveys of biodiversity or even the mapping of land use classes from remote sensing are expensive activities, modelling approaches such as the SALCA-BD expert system provide an undoubted advantage. Land use impact assessments on biodiversity are useful for e.g. comparing impacts at various scales (field, farm, region) or elaborating measures that benefit biodiversity.

Beyond the data used in this study, SALCA-BD computes scores for eleven ISGs that are combined in one biodiversity score taking into account the total species richness of the individual ISGs and their position in the food web. The question arises then whether all ISGs are indispensable to model impacts of agricultural activities on biodiversity. The results of the validation study confirm that multiple ISGs are necessary to encompass as much as possible of biodiversity, as we found distinct patterns of relationship between the expert system scores and the measured species richness for arable crop flora, grassland flora, spiders, and wild bees, depending on the scale. While all were positive and significant at field scale, relationships were no more significant for mobile groups, namely spiders and bees at farm scale. This suggests that mobile ISGs do likely react to typical beyond field parameters the expert system does not take into account such as e.g. edge effects, spatial arrangement, connectivity, or fragmentation which effects have been demonstrated in several studies (e.g. Clough et al 2005; Fahrig et al 2011; Gaujour et al 2012; Kremen et al 2007). Generally speaking, transfer of findings from one biodiversity indicator to another is often hazardous given that no single indicator can be derived that surrogates for all other organisms in terms of its reaction to farming operations as emphasized in previous studies (Büchs 2003; Lund and Rahbek 2002; Lüscher et al 2014; Lüscher et al 2015). In their evaluation of the completeness of scope and high biodiversity representation, Curran et al. (2016) evaluated the SALCA-BD expert system as the second best approach of 20 biodiversity indicator models in LCA frameworks.

Our validation process was directed at the core of the SALCA-BD expert system, i.e. the suitability of land use classes as habitats and the effects of agricultural practices on species richness. Results reflected the main issues of this approach. For example, the stronger positive relationships between OSD scores and species richness of arable crop flora and grassland flora than of spiders and bees could be related to the fact that land use class demarcation generally relied on vegetation characteristics. The inclusion of the land use class as varying intercept in all best models at field scale indicated the importance of an appropriate land use classification. For the aggregation from field scale to farm scale, the SALCA-BD expert system combined scores of each land use class based on the relative proportion of the land use class area to the total farm area. In this way, scores of small land use classes, i.e. most semi-natural land use classes, contribute little to the scores at farm scale. However, these land use classes often contribute much to the total farm species richness. Further, in the aggregation algorithm, important parameters of spatial arrangement are not included as mentioned before. Consideration of the spatial configuration of the land use classes in the expert system would certainly improve score prediction by ground survey data, especially for mobile organisms as scores computed at field scale are aggregated at farm scale. This is particularly important because assessment at farm scale is relevant to compare different management strategies and to directly address the farmers as important decision makers for the agricultural area. Incorporation of spatial characteristics into the SALCA-BD expert system for real farm assessments is promising but would require the extension of the life cycle inventory to include cartographic information.

Limitations that can explain the large range of the species richness observed for a constant score obtained with the expert system are the wider landscape context and the temporal dynamic. For example, a decline in biodiversity at a landscape level beyond the expert system boundaries may contribute to the decline of the local – field or farm – biodiversity despite biodiversity friendly farming practices. Similarly, the expert system assumes an instantaneous response of species diversity to agricultural practices although farming effects may take years to fully impact as for instance low-input management. Here, in general, patterns confirmed that the direction, extent and combination of coefficients assigned to different agricultural practices were reflected in the data from field surveys.

5 Conclusions

An indicator of biodiversity grasps just a piece of the whole entity. So, validation of such an indicator needs appropriate data to clearly address the respective piece of biodiversity. Here, the availability of empirical species data allowed a validation of the SALCA-BD biodiversity indicator and revealed its strengths and potential for improvement. Although validation was restricted to four indicator species groups (ISG) of the eleven ISGs included in the SALCA-BD biodiversity indicator, differences among groups were pointed out and indicated their complementary value. The study highlighted that modelling species richness at smaller spatial scales was more successful than at larger scales. Detailed land use classes (e.g. types of cultivated arable crops or grassland under cutting vs. grazing management) were good predictors of the variability in observed species richness across the European study regions. However, there is still high potential for improvement, especially regarding semi-natural elements, which may be of marginal agricultural value but contribute considerably to species richness.

In the framework of LCA, not only the regional but also the global scale is relevant. Regarding land use impact pathways, appropriate biodiversity indicators for various levels of land use classification from detailed to very general would be required. Considering species richness as a proxy for terrestrial biodiversity, our validation at a small spatial scale shows the huge amount of information required to predict species richness at small scale, i.e. areas from a few square meters up to a few square kilometers. Coarser land use classes (e.g. biomes) to expend at larger scales would cause a substantial loss of information and increased uncertainty in model results. Furthermore, due to the considerable variability among regions as demonstrated here, assigned coefficients in the model should be adapted to take into account different species pools and land use characteristics. Nevertheless, the validated biodiversity indicator, i.e. the overall species diversity score (OSD) is dimensionless and can be used to express relative differences among studied entities. Extending the model framework to non-agricultural areas and activities such as forestry, mining, transport, processing, consumption and waste management would require a reconsideration and adaptation of the set of ISGs since the ISGs were selected specifically for agricultural areas. Furthermore, land transformation impacts would need to be included in the method. For the future, a comprehensive biodiversity assessment in LCA will remain a huge challenge. To take steps forward to this goal, our study revealed that a standardized and detailed land use classification, accompanied by detailed land management information, is a clear advantage.

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Table 1 Overview of data included in analyses. Latitude and longitude are the coordinates of the centroid of all fields within a region. MAT is the mean annual temperature. Altitude is expressed in m asl, i.e. meters above sea level. Ecoregions according to Olson et al (2001).

Region	**AT**	**BG**	**CH**	**DE**	**FR**	**GB**	**HU**	**NO**
Geographic region	Marchfeld	Rhodope Mountains	Obwalden	Southern Bavaria	Gascony	Wales	Homok-hátság	Hedmark
Country	Austria	Bulgaria	Switzer-land	Germany	France	United Kingdom	Hungary	Norway
Latitude	48.278	41.687	46.885	48.416	43.351	52.474	46.824	62.394
Longitude	16.724	24.569	8.197	11.345	0.792	-3.496	19.476	10.951
Farm type	Arable crops	Grassland	Grassland	Mixed	Arable crops	Grassland	Mixed	Grassland
Altitude [m asl]	140 - 180	900 - 1400	605 - 1133	350 - 500	197 - 373	450 - 1085	93 - 168	488 - 886
Ecoregion	Pannonian mixed forests	Rodope montane mixed forests	Alps conifer and mixed forests	Western European broadleaf forests	Western European broadleaf forests	Celtic broadleaf forests	Pannonian mixed forests	Scandinavian Montane Birch forest and grasslands
Rainfall [mm per year]	560	900	1300	800	680	1500	550	470
MAT [°C]	9.5	7.5	5.6	8.5	13	10	10.4	0.4
No. of farms	16	16	19	16	16	19	18	12
No. of fields (fields with information about occupation interventions)	123 (52)	146 (84)	139 (63)	129 (85)	224 (131)	224 (88)	159 (100)	119 (64)

Table 2 Results of best-fit negative binomial generalized mixed effects models for four indicator species groups. Values are log-transformed (natural logarithm). The intercept indicates the general species richness of the indicator species group under study. The slope indicates the direction (positive or negative) of the relationship between species richness and overall species diversity scores and its strength. For the random part, X indicates that a random intercept or slope is included in the best model, - indicates exclusion. The negative binomial parameter informs about the variance of the model. Field scale and farm scale A include exclusively fields for which information about agricultural practices was available. Farm scale B includes all fields, i.e. arable crops, grasslands and semi-natural habitats. Abbreviations for the indicator species groups: Afl = Arable crop flora, Gfl = Grassland flora, Spi = Spiders, Wbe = Wild bees. P-values were calculated from likelihood-ratio tests and significances indicated as * = $p < 0.05$, ** = $p < 0.01$ and *** = $p \leq 0.001$. Random effect coefficients were given as standard deviation of the corresponding varying intercepts and slopes, respectively

		Fixed part		Random part			
	Indicator species group (ISG)	Intercept (Std. Error)	Slope (Std. Error)	Land use class intercept	Region intercept	Region slope	Neg. binomial parameter (Std. Error)
Field scale	Afl	0.375 (0.65)	0.131** (0.041)	X	-	X	6.823 (1.355)
	Gfl	2.283 (0.214)	0.056** (0.017)	X	X	X	11.113 (1.118)
	Spi	1.357 (0.238)	0.033* (0.015)	X	X	-	6.548 (0.764)
	Wbe	-0.088 (0.344)	0.046* (0.021)	X	X	X	3.512 (0.53)
Farm scale A	Afl	2.156 (0.323)	0.052* (0.024)		-	X	8.045 (2.244)
	Gfl	3.02 (0.283)	0.074*** (0.019)		X	-	9.51 (1.538)
	Spi	2.445 (0.374)	0.049 (0.028)		X	-	7.418 (1.282)
	Wbe	1.671 (0.452)	0.02 (0.026)		X	-	3.725 (0.76)
Farm scale B	Afl	2.44 (0.292)	0.041*** (0.012)		X	-	8.155 (2.122)
	Gfl	4.072 (0.129)	0.02 (0.013)		-	X	12.636 (1.944)
	Spi	3.568 (0.215)	0.005 (0.013)		X	-	12.409 (2.218)
	Wbe	2.435 (0.337)	-0.003 (0.018)		X	-	8.812 (2.063)

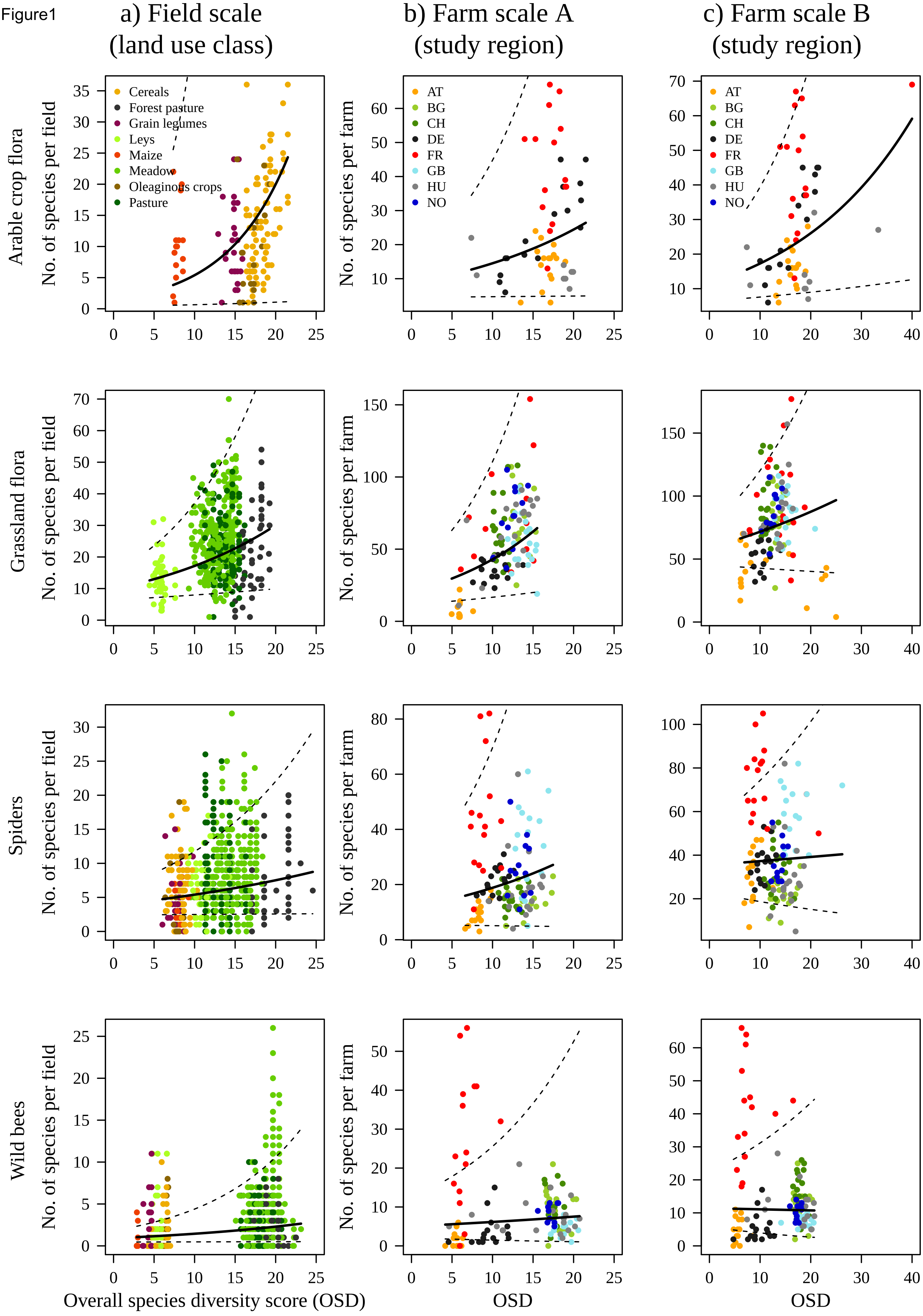
Table 3 Results of negative binomial generalized linear models for four indicator species groups in eight regions. Values are log-transformed (natural logarithm). The intercept indicates the general species richness of the indicator species group under study. The slope indicates the direction (positive or negative) of the relationship between species richness and overall species diversity scores and its strength. Theta is the parameter to assess the variance of the negative binomial generalized linear model. Data are analyzed at field scale and include exclusively fields for which information about agricultural practices was available. Abbreviations for the indicator species groups: Afl = Arable crop flora, Gfl = Grassland flora, Spi = Spiders, Wbe = Wild bees. [a)] = the iteration limit was reached for calculating theta. P-values were calculated from likelihood-ratio tests and significances indicated as * = $p < 0.05$, ** = $p < 0.01$ and *** = $p \leq 0.001$

Indicator species group (ISG)	Region	Intercept (Std. Error)	Slope (Std. Error)	Theta (Std. Error)
Afl	AT	1.878 (0.465)	-0.003 (0.029)	5.019 (2.095)
	BG	NA	NA	NA
	CH	NA	NA	NA
	DE	1.663 (0.292)	0.063*** (0.017)	5.217 (1.807)
	FR	1.35 (0.489)	0.078** (0.028)	6.671 (1.743)
	GB	NA	NA	NA
	HU	3.083 (0.298)	-0.035 (0.018)	[a)]
	NO	NA	NA	NA
Gfl	AT	2.898 (1.722)	-0.14 (0.289)	4.924 (3.341)
	BG	3.983 (0.542)	-0.063 (0.04)	4.675 (0.929)
	CH	2.555 (0.182)	0.084*** (0.014)	57.403 (25.821)
	DE	2.52 (0.134)	0.036** (0.012)	84.613 (93.729)
	FR	2.109 (0.252)	0.092*** (0.018)	9.041 (2.209)
	GB	3.334 (0.3)	-0.026 (0.022)	9.456 (2.141)
	HU	2.565 (0.158)	0.028* (0.012)	12.306 (3.099)
	NO	2.313 (0.223)	0.072*** (0.015)	12.354 (3.232)
Spi	AT	-0.645 (0.527)	0.226*** (0.059)	5.483 (2.827)
	BG	1.381 (0.364)	0.004 (0.025)	19.405 (16.474)
	CH	1.559 (0.319)	0.027 (0.023)	[a)]
	DE	1.529 (0.178)	0.053*** (0.015)	18.966 (10.492)
	FR	1.338 (0.14)	0.073*** (0.011)	6.741 (1.586)
	GB	2.847 (0.265)	-0.009 (0.018)	9.055 (2.681)
	HU	0.699 (0.484)	0.067* (0.034)	1.437 (0.288)
	NO	1.912 (0.296)	0.016 (0.019)	5.392 (1.622)
Wbe	AT	-0.232 (1.441)	-0.102 (0.268)	0.419 (0.236)
	BG	3.005 (0.899)	-0.109* (0.051)	20.034 (24.462)
	CH	0.865 (0.877)	0.033 (0.048)	[a)]
	DE	-0.953 (0.354)	0.057* (0.024)	0.979 (0.411)
	FR	0.534 (0.171)	0.089*** (0.012)	1.448 (0.29)
	GB	0.099 (0.845)	0.026 (0.046)	9.617 (11.306)
	HU	0.18 (0.367)	0.021 (0.021)	1.649 (0.509)
	NO	1.454 (0.991)	-0.015 (0.054)	5.502 (2.958)

Figure caption

Fig. 1 Relationships between overall species diversity scores and observed species richness for the four indicator species groups. X-axes show the calculated overall species diversity scores by SALCA-BD, y-axes show the number of observed species. Black lines indicate predicted values of best-fit negative binomial generalized mixed effects models over all regions (back-transformed). Dashed lines indicate the predicted values ± two standard errors (≈ 95% confidence interval). Fig. 1a (left column) shows the data at field scale. The colors indicate the eight land use classes, which are included in the reduced data set. Fig. 1b (middle column) shows the data of the reduced data set at farm scale, i.e., Farm scale A. The colors indicate the eight study regions. Fig. 1c (right column) shows all data at farm scale, i.e. Farm scale B. The colors indicate the eight study regions.

Figure1


a) Field scale
(land use class)
b) Farm scale A
(study region)
c) Farm scale B
(study region)
Arable crop flora
Grassland flora
Spiders
Wild bees
No. of species per field
No. of species per farm
Cereals
Forest pasture
Grain legumes
Leys
Maize
Meadow
Oleaginous crops
Pasture
AT
BG
CH
DE
FR
GB
HU
NO
Overall species diversity score (OSD)
OSD