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Land use intensity and landscape complexity—Analysis of landscape characteristics in an agricultural region in Southern Sweden

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ABSTRACT

It is generally recognised that agricultural intensification has lead to simplification of landscape structure, but it has not been clarified if this is a ubiquitous relationship. That is, it has been an open question whether agricultural intensity and landscape simplicity should be regarded as one single or as two separate dimensions. To evaluate this we analysed landscape data in 136 different 1 km $\times$ 1 km study sites and within a buffer zone of 2 km around each site (i.e. approximately 5 km $\times$ 5 km). The sites were distributed over a large part of the region of Scania, southernmost Sweden, an area dominated by agriculture but with large variation in both intensity and complexity. We used spatially explicit digital data on land use, digitised aerial photographs, field surveys of landscape elements and agricultural statistics. Two separate factor analyses, one for each scale of measurements (1 km and 5 km), suggest that there are five and three relevant factors for each scale respectively. At the 1 km scale, the first factor can be interpreted as describing the intensity of land use in the form of proportion arable land which is highly correlated to crop yield. The second and third factors are more connected to landscape structure and amount of small patches of semi-natural habitats. The fourth and fifth factors contain one major variable each: proportion pasture and leys respectively. The division of intensity and complexity related variables is less clear at a larger spatial scale. At the 5 km scale, factor 1 is defined almost identically as at the 1 km scale. However, factors 2 and 3 are interpreted as descriptors of dairy and livestock farming systems but also include structural variables. Our analyses suggest that land use intensity and structural complexity of landscapes are more or less separate landscape level factors, at least at smaller spatial scales. This is important to bear in mind, especially when trying to explain patterns of biodiversity change in agricultural landscapes.

1. Introduction

In Europe and elsewhere agricultural development – modernisation and intensification – has accelerated during the last 50 years. This has lead to a transformation of landscape structure, generally towards a simpler one, via changes in management and land use (Benton et al., 2003). These changes act over several spatial scales where local changes for example include larger fields and changes of management practises (e.g. increased use of agrochemicals, choice of crops and rotation schemes) (Benton et al., 2003; Tscharntke et al., 2005). At a much larger scale, acting over the whole EU, the common agricultural policy (CAP) among other things affects the choice of crops and the amount of fallow via subsidy systems (Donald et al., 2001; Wretenberg et al., 2007).

During the last half-century many groups of organisms connected to the agricultural landscape have declined dramatically (Benton et al., 2003; Tscharntke et al., 2005). A decline in numbers is, for example, evident for farmland birds (Shrubb, 2003; Lindström and Svensson, 2005) as well as for plants and insects (Baessler and Klotz, 2006; Biesmeijer et al., 2006; Fitzpatrick et al., 2007). From a biodiversity perspective, intensification results in loss and fragmentation, as well as decreased quality, of natural and semi-natural habitats. Several authors suggest that the loss of spatial and temporal heterogeneity, i.e. farmland becoming ever more simplified, is the general cause of the decline in biodiversity (Meek et al., 2002; Benton et al., 2003; Shrubb, 2003; Pywell et al., 2005; Tscharntke et al., 2005). Also land use intensity has been related with declining biodiversity (Kleijn et al., 2009). The goal of agricultural intensification is to increase the yield per unit area, and intensification can thus be estimated from crop yield data

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(Donald et al., 2001; Vepsäläinen, 2007). The degree of landscape heterogeneity (complexity) is a result of the mix of habitat types within an area, i.e. the number of land use classes and the distribution and configuration of these (Turner et al., 2001; Vepsäläinen, 2007).

Intensification and loss of heterogeneity are often considered two sides of the same coin. Several studies on the effect of agricultural activities on biodiversity in a landscape perspective have used different definitions of and proxies for land use intensity and landscape structure, e.g. the proportion of arable land (per landscape and per farm), the proportion of permanent pasture or semi-natural habitats, size of arable fields, input of inorganic fertilisers and pesticides, crop harvest data, number of land use classes within an area or diversity indexes of land use (Donald et al., 2001; Steffan-Dewenter, 2002; Jeanneret et al., 2003; Kerr and Cichlar, 2003; Roschewitz et al., 2005; Sandkvist et al., 2005; Schweiger et al., 2005; Baessler and Klotz, 2006; Rundlöf and Smith, 2006; Firbank et al., 2008). Yet other metrics used to represent structure are for example length of and structural indices on non-crop field boundaries and semi-natural habitats within a landscape (Schweiger et al., 2005; Concepción et al., 2007).

To find one single proxy variable for both intensity and complexity at least two requirements must be fulfilled. First, this proxy needs to be related to intensity and complexity in a straightforward manner. Second, intensity and complexity need to be monotonically related to each other. Firbank et al. (2008) suggest that agricultural landscapes can be described along three axes: large scale land use, local field management and landscape structure. A study in northern Germany (Roschewitz et al., 2005) showed that proportion arable land per landscape was linearly related to land use diversity (referred to as complexity) but not correlated with the proportion arable land per farm (farm specialisation).

It might be possible to separate intensity related components (such as proportion arable land and harvest data) from structural ones (such as field size, amount of small semi-natural habitats and land use diversity). In an area where landscapes span a wide range of both intensity and complexity we may thus find structurally complex landscapes with intense farming. This allows detection of independent variation of at least these two landscape factors. Being able to separate these two dimensions of variation would allow us to design landscape scale study systems (Herzog, 2005; Rundlöf et al., 2008), to evaluate the effects of structural and complexity related components on biodiversity on a landscape scale, independently of field level intensity.

How important different variables are accounting for variation across landscapes may depend on the scale, i.e. size of the study sites analysed. Purtauf et al. (2005) showed that at small and medium scales (1 km × 1 km–3 km × 3 km), management variables and local site parameters (e.g. fertiliser application, pH-value) explained most of the variation between sites, while at a larger scale (4 km × 4 km) land use variables (% of land cover) explained more. The same authors also showed that the strength of correlations between variables increased with spatial scale. Furthermore, many organisms can be expected to react to or be affected by different mechanisms at different spatial scales. It would therefore be valuable to look at data on more than one spatial scale both when analysing landscape data only and when biodiversity data is added.

The purpose of this study was to investigate if it is possible to distinguish measures of agricultural intensity from measures of landscape complexity and if so, which proxies might be used to represent them. Furthermore, we investigate if the interrelationship between measures of complexity and intensity are dependent on the scale at which the analysis is performed. We perform these analyses for the agricultural landscapes of Scania (southernmost Sweden), because this region has an unusually large variation in agricultural landscapes over a small area (ca. 120 km × 120 km). These analyses constitute an important background to any further analysis in which spatial or temporal variation in biodiversity is to be explained by the ongoing intensification and simplification of agricultural landscapes (cf. Benton et al., 2003).

2. Methods

This study is based on land use data and agricultural statistics from several sources spanning over the period 1995–2002. The study system was originally designed to survey farmland birds (Svensson, 2001), but the bird data is not presented here. Two study sites of 1 km × 1 km each were selected from each 10 km × 10 km grid square of the Swedish National Grid System and were therefore systematically distributed over the region of Scania (approx. 56°N, 13°30′E), an area of approximately 120 km × 120 km (Fig. 1).

2.1. Habitat inventory

Detailed habitat data was collected during a survey 1995–2002. The inventory was conducted by volunteers and field assistants, who made an inventory of habitats and land use classes (Svensson, 2001). Larger continuous areas of forest were excluded from the survey. From this material we have collected information on the presence of small habitats with patches of semi-natural vegetation such as stonewalls and ditches.

2.2. Digital information from the Swedish Board of Agriculture

We have utilised information from the Integrated Administration and Control System (IACS, Blockdatabasen), a yearly updated database on all registered farmland fields in Sweden, including spatially explicit data on crops and other land uses on farmland (pasture, fallow, tree plantations, etc.). In IACS, fields are reported in units of "blocks", which typically consist of one or several adjacent fields surrounded by a border that can be identified on an aerial photograph. However, within the blocks the area covered by individual crops is known. To match the time of the habitat/bird inventory we used block data from 1999 and extracted information on crops as well as the size of blocks of fields and the proportion of arable land. We define farmland as all blocks in the database with either annual crops, leys, pastures or fallow. Block data was also used to calculate the amount of non-crop field borders. Since the delineation of fields provided by this digital dataset is based on border structures seen on aerial photographs, they are more in line with how fields are actually divided by non-crop border habitat, compared to the inventory maps created during bird/habitat surveys where all land parcels were drawn (Persson, pers. obs.). We used a template border width of 2.4 m to calculate border area, since this is the average width found by two independent habitat inventories in Scania (Persson and Rundlöf, unpublished data). Their analysis showed that the width of borders did not vary between different types of landscapes, defined as homogenous or heterogenous according to criteria similar to the ones used here (mixed model, difference between two landscape types when ca 900 borders were measured at 10 sites, $F_{1,8} = 0.56$, $P = 0.5$).

It should be noted that according to the classification we have used, pastures and leys are quite different. Pastures are practically permanent, semi-natural grasslands used exclusively for grazing. They may be fertilised but often they are not, or at least not much. In contrast, leys are rotational crops where grass, sometimes mixed with clover, is cultivated for grazing or hay or silage production.

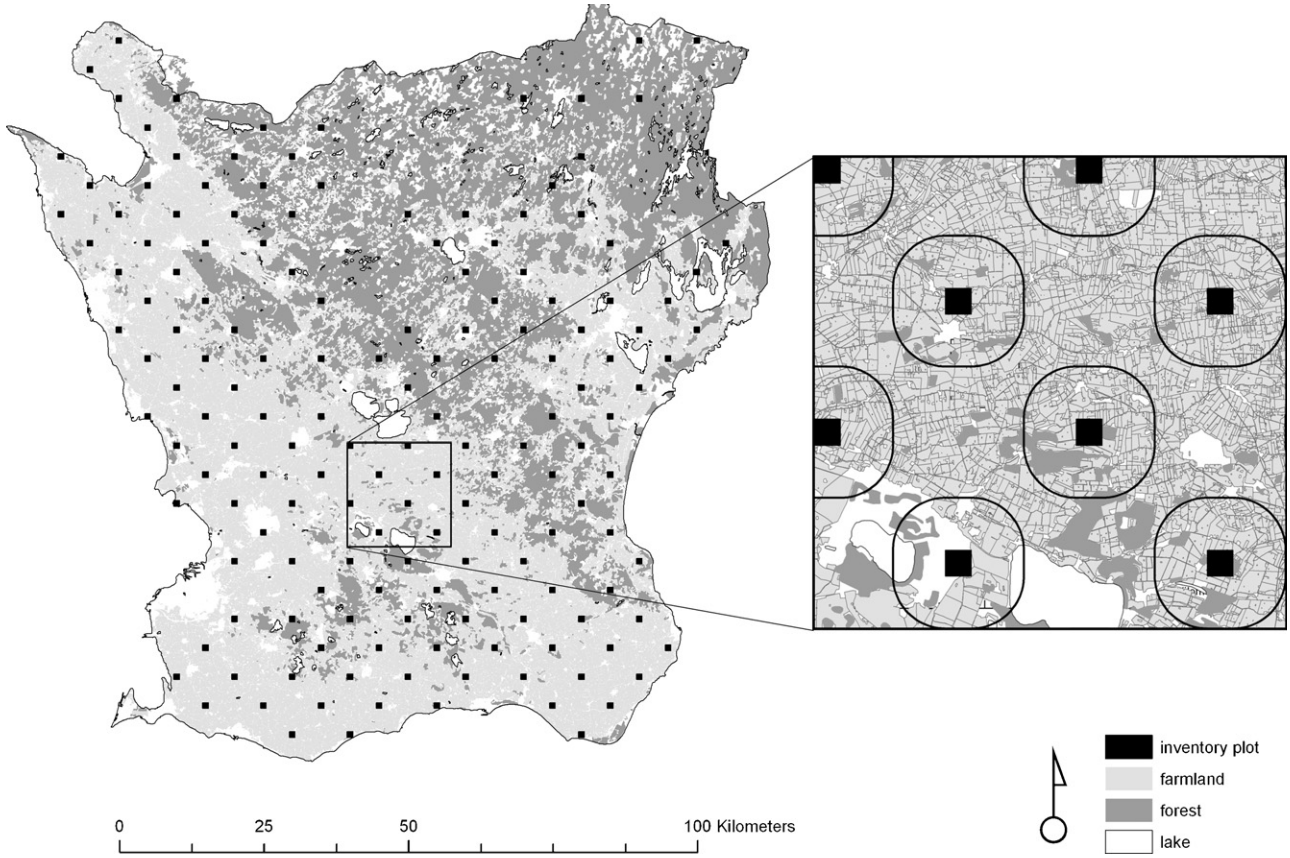

Fig. 1. Map of the study area; the region of Scania and the study sites used in the analyses. The inserted picture shows sites with 2 km buffer zones. Farmland fields, forest and lakes are drawn.

Typically, a field is used as ley for at least 2 and sometimes up to 5 years in sequence. After that it is used for other crops for some years.

2.3. Aerial photographs

By studying aerial photographs (black and white orthophotos from the Swedish Land Survey, Lantmäteriet) of each inventory plot, semi-natural habitats such as stone walls, ditches, small wood lots and single trees, field islands, permanent pastures and grasslands could be identified or verified and digitised. This gave us a detailed dataset of small, semi-natural habitats at the 1 km scale.

2.4. Corine land use data

From the satellite data of the EU programme CORINE (Coordination of Information on the Environment), data on forests, wetlands, water bodies and built-up areas for the concerned areas was extracted and used to complement information from the above mentioned sources. CORINE data is available at a 25 m $\times$ 25 m resolution.

2.5. Statistics on harvest

We used data from Statistics Sweden on normalised harvest of spring sown barley in 2006. The normalisation of harvest data results in a more robust estimate not affected by year to year variation. It describes the harvest expected in 2006 based on data for the past 15 years and so the in-data spans the whole period (1995–2002) of this study. The geographical basis for calculations of harvest is the 17 "harvest regions" of Scania; administrative regions originally based on collections of neighbouring parishes.

2.6. Data treatment

From the original 163 study sites we selected 136 sites, all containing more than 10% farmland and less than 50% of built-up areas or water bodies. All data was digitised and processed in ArcGis 9.1 (ESRI). The total area of different land use classes, field sizes and area of border habitats per landscape were calculated (Table 1). We also used a buffer zone of 2 km around each inventory plot (i.e. approximately 5 km $\times$ 5 km but with rounded corners, 2156 ha (Fig. 1)), and used block data and CORINE data to calculate average field size and area of major land use classes (Table 1). For calculation of average field size at the 1 km scale, fields were weighted by the proportion being contained within the landscape. In this way the influence of fields with only a small proportion actually within the landscape was lowered, while still being included in the calculation. All variables used in the analyses are briefly explained in Table 1.

Crop diversity was calculated for both spatial scales with the Simpson Diversity index calculated as $-\ln(D)$, where D is the sum of squared proportions of each crop type per study area (Magurran, 2004). Crops were classified as belonging to one of 11 classes of crops; spring sown cereals (mostly barley *Hordeum vulgare*, oat *Avena sativa*, but also some wheat *Triticum aestivum*), autumn sown cereals (mostly wheat and rye *Secale cereale*), sugar beet (*Beta vulgaris*), oilseeds (almost exclusively autumn sown oilseed rape *Brassica napus*), leys (cultivated grass and sometimes clover *Trifolium* sp.), potato (*Solanum tuberosum*), pea (*Pisum sativum*), fallow, pasture, other low crops (vegetables and berries), and other high crops (maize *Zea mayz*, fruit orchards and *Salix* sp.). We chose

Table 1
Definitions and characteristics of variables for the 136 sites analysed, at the two scales (1 km and 5 km) of analysis.

Variable	Explanation	1 km				5 km			
		Mean	sd	Min	Max	Mean	sd	Min	Max
Prop. farmland	Proportion crops, leys, pasture and fallow per landscape	0.717	0.254	0.122	0.987	0.675	0.264	0.063	0.976
Prop. crops	Proportion annually tilled land per landscape	0.458	0.320	0	0.953	0.456	0.284	0.002	0.938
Crop diversity	$-\ln(\text{Simpson}\,D)$ of crops divided into 11 categories	2.05	0.41	1.00	2.78	2.42	0.32	1.48	2.93
Field islands	Proportion of semi-natural habitat islands within farmland fields	0.003	0.006	0	0.040				
Contagion	Calculated in Fragstats on four land use classes: arable, semi-natural, water, forest	71.6	11.2	47.5	92.8				
Land use diversity	$-\ln(\text{Simpson}\,D)$ of arable, semi-natural, water, forest	0.538	0.331	0.042	1.182	0.774	0.372	0.109	1.857
Field size	Mean size of farm fields (ha)	12.0	16.5	0.9	108.9	9.6	6.6	1.2	29.3
Border area	Total area of field borders, stonewalls, ditches, road verges (ha)	0.030	0.011	0.009	0.068	0.028	0.009	0.005	0.051
Trees and hedges	Total area of tree- and hedgerows and solitary trees (ha)	0.037	0.029	0.002	0.227				
Prop. leys	Proportion of leys per landscape	0.116	0.140	0	0.771	0.093	0.072	0.006	0.327
Prop. pasture	Proportion permanent pasture per landscape	0.089	0.135	0	0.707	0.071	0.063	0	0.352
Spring barley	Normalised (15 year intervals) data on yield if spring sown barley (kg/ha)	5049	983	2591	6344	5049	983	2591	6344

to use only the Simpson index for diversity after we had made preliminary analyses showing that this index was very strongly correlated with the Shannon–Weaver index ($r = 0.98$, $p < 0.0005$ at both scales) and with total number of crops in a landscape (1 km: $r = 0.71$, $p < 0.0005$; 5 km: $r = 0.82$, $p < 0.0005$). The reason for choosing the Simpson index was that it had better statistical properties than the alternatives.

Land use diversity was calculated for both spatial scales with the Simpson Diversity index, as above, and land use was classified as belonging to one of four categories; arable land (annually tilled fields and leys), forest (larger areas of forest, production forest and small wood lots), wetland and water or semi-natural habitats (permanent pasture, non-crop border habitats, tree and hedge rows, solitary trees). Again, the Simpson index was chosen because it had better statistical properties than the Shannon–Weaver index, and they were nearly perfectly correlated (1 km: $r = 0.99$, $p < 0.0001$; 5 km: $r = 0.88$, $p < 0.0001$).

Fragstats 3.3 (McGarigal et al., 2002) was used for the calculation of another landscape index, Contagion, on raster data (vector to raster conversion in ArcGis, grid cell size 1 m), using the same four land use categories as mentioned above. This index was calculated only at the 1 km scale. The Contagion index is based on the probability of adjacent pixels belonging to the same category as the focal one and thus expresses to what degree the land use categories are inter-dispersed (McGarigal et al., 2002). We used a resolution of 1 m for the Fragstats calculations. The data extracted and used in the analyses is presented in Table 1. Where proportions of land uses were used they were arcsine-square-root transformed to normalise data and to avoid variance to be associated with the mean. Contagion is one of many landscape indices that can be calculated. We chose to use this, over the alternatives, because it has often been used in other studies, and because it is intuitively quite easy to understand.

The variables we used for analyses are presented in Table 1. A priori we expect that at least proportion farmland and proportion crops should be related to intensity. Similarly, we expect that field islands, Contagion, Simpson land use diversity, field size, border area, and area of trees and hedges should represent complexity.

Statistical analyses were done in R 2.8.1 (R Development Core Team, 2008) with the procedures factanal and cor in package stats, and gls in package nlme. We ran two separate factor analyses, one on each spatial scale of measurement (1 km and 5 km), which included 11 and 8 variables respectively (Table 1). To maximise the interpretability of the factors we used the Promax rotation method at the 1 km scale. This method allows factors to deviate from orthogonal positions so as to better represent the variables in the analysis, and it often results in variables separating more clearly between factors (Abdi, 2003). Because factors are not orthogonal we also ran correlations between the resulting factors to check for relations. At the 5 km scale we used Varimax rotation, as preliminary analyses showed that it produced factors very similar to the Promax method, but Promax factors became heavily correlated.

Because we believe that there are underlying patterns in the dataset, which may be detected via combinations of variables, we decided to use factor analysis instead of repeated separate correlations of landscape variables and agricultural statistics. This method has the advantage of letting us combine variables into a set of factors, which are more or less independent depending on the rotation method used. The factors are interpreted through the loadings (correlations) they have on the original variables (Quinn and Keough, 2002). Another and similar method is the principal component analysis, PCA. However, that method does not assume underlying patterns in the dataset and instead extracts components in order to explain as much of the variation in the material as possible (Quinn and Keough, 2002; Suhr, 2003).

We use the yield of spring barley as an indicator of agricultural intensity. We do not include it in the factor analyses, but rather test how the resulting factors are related to the yield of barley. We expect that in particular the total proportion of farmland and that of crops are measures of intensity, whereas the structural indices – land use diversity and contagion – ought to be related to complexity. The same should be true for field size, border area, tree rows and hedges. For the remaining variables it is more difficult to predict in advance if they will be related to a complexity or an intensity dimension.

In order to evaluate how the factors were related to intensity we ran generalized least squares regression (GLS) models with the harvest of spring barley as the dependent variable and the factors, their two-way interactions and quadratic terms as independent

Table 2
Results of factor analysis at the 1 km scale in the form of factor loadings, eigenvalues and the variance explained by factors. Bold numbers indicate the main loading for each variable.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Prop. farmland	**1.002**	−0.244	0.171	0.124	0.237
Prop. crops	**0.734**	−0.105	0.086	−0.219	−0.246
Crop diversity	**0.614**	0.242	0.098	0.015	−0.273
Field islands	**0.369**	0.108	−0.053	0.042	−0.059
Contagion	0.114	**−0.864**	0.036	0.006	−0.095
Land use diversity	−0.121	**0.874**	−0.055	0.053	0.117
Field size	**0.690**	−0.030	**−0.537**	0.003	0.163
Border area	0.172	−0.090	**0.939**	0.072	0.112
Trees and hedges	0.090	0.104	**0.534**	−0.074	0.092
Prop. leys	−0.035	0.043	0.088	**0.972**	−0.120
Prop. pasture	0.028	0.191	0.136	−0.115	**0.796**
Eigenvalues	2.60	1.71	1.54	1.04	0.91
% Cumulative variance explained	24	39	53	63	71

variables. We accounted for spatial autocorrelation in the data by adding a spatial spherical correlation structure (Dormann et al., 2007). The spherical correlation structure fit the data better than alternative structures. For each spatial scale, we ran all possible models with the factors, their interactions and quadratic terms, and for each scale we identified the best model based on the AIC value (Burnham and Anderson, 2002).

3. Results

Based on the variation explained by each factor, we retained factors with eigenvalues above or close to 1, resulting in five factors at 1 km and three factors at the 5 km scales respectively (Tables 2 and 3). At the 1 km scale we also tested retaining four and six factors, but since four factors explained substantially less total variation and the sixth factor had very low eigenvalue (0.76) we chose to keep five.

At both spatial scales (Tables 2 and 3), the first factor includes proportion of farmland, the proportion of annual crops per landscape, the size of fields and crop diversity. In the 1 km scale analyses, the area of field islands were not clearly bound to any factor but had its highest loading on factor 1 (this variable was not available at the 5 km scale). At the 1 km scale factor 2 contained the indices on structure and land use diversity; Contagion and Simpson land use diversity. At the 5 km scale factor 2 contained land use diversity together with proportions of pasture and leys. At the 1 km scale factor 3 represented the amount of field borders and other border habitats (stone walls, ditches, etc.), trees and hedgerows and the size of fields. At the 5 km scale factor 3 represented field borders and the proportion of leys in the

Table 3
Results of factor analysis at the 5 km scale in the form of factor loadings, eigenvalues and the variance explained by factors. Bold numbers indicate the main loading for each variable.

	Factor 1	Factor 2	Factor 3
Prop. crops	**0.814**	−0.541	0.202
Crop diversity	**0.721**	−0.046	0.253
Prop. farmland	**0.850**	−0.338	0.373
Field size	**0.952**	−0.246	−0.168
Land use diversity	−0.221	**0.741**	−0.098
Prop. pasture	−0.127	**0.813**	0.124
Prop. leys	−0.227	**0.625**	**0.566**
Border area	0.476	0.008	**0.877**
Eigenvalues	3.152	2.070	1.386
% Cumulative variance explained	39	65	83

Table 4
Correlations between factors from the factor analysis at the 1 km scale and between factors. R values and level of significance shown (*$P > 0.05$, **$P > 0.01$, ***$P > 0.001$).

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 2	0.318***				
Factor 3	0.008	−0.297***			
Factor 4	0.070	−0.075	−0.239**		
Factor 5	0.314***	−0.184*	0.009	−0.170*	

landscape. To use the same set of variables as for the 5 km scale, we also ran the 1 km analysis with only field borders (i.e. no information on other semi-natural habitats). Since it resulted in the same structure of the factors (data not shown), we chose to use the more detailed dataset for further interpretations. The proportions of leys and pastures were represented by one factor each in the 1 km analysis (factors 4 and 5, respectively), while at the larger scale leys, pastures and land use diversity were combined into factor 2 and leys and field borders were combined into factor 3.

As we have used the Promax rotation method at the 1 km scale, factors are not completely orthogonal but instead allow a cleaner split of the variables between factors, increasing interpretability. Correlations between factors were moderate (Table 4; highest R^2 value 0.10), and hence we see no problem in using the Promax rotation for the interpretability of the factors.

We tested to what extent the different factors were related to the yield of spring barley using GLS. At the 1 km scale the best GLS model showed that harvest of spring barley was strongly related to only factor 1 (Standardized regression coefficient $\beta_1 = 0.15$, $t_{134} = 4.30$, $P < 0.0005$; Fig. 2A). The second best model had a ΔAIC = 6.2, and thus fit much worse (Burnham and Anderson, 2002). At the 5 km scale the relation is even stronger, with spring barley being related to all three factors ($\beta_1 = 0.44$, $t_{132} = 6.58$, $P < 0.0005$; $\beta_2 = -0.16$, $t_{132} = 3.21$, $P < 0.002$; $\beta_3 = 0.13$, $t_{132} = 2.89$, $P < 0.004$; Fig. 2B–D). The second best model had a ΔAIC = 1.8, and was similar to the best model except it did not contain factor 3. All other models had $\Delta\text{AIC} \gg 3$.

4. Discussion

4.1. Intensity versus complexity

In this study we show that intensity and complexity are to a large extent independent landscape factors. The first factor generated by factor analysis of farmland landscape variables was related to the proportion of landscape under intense land use and to harvest data. The second and third factors contained variables connected to structure and complexity; border habitats, field size and land use diversity and configuration. Naturally, the result of a factor analysis depends on the variables included. The variables we have used are a mixture of what we believe are intensity related ones (proportion of farmland and annual crops), structural ones (field size, amount of small habitats and linear elements and diversity and configuration of land use classes) and in addition proportion pastures, leys and crop diversity. The proportion of farmland per landscape has previously been used as a descriptor of landscape complexity (e.g. Roschewitz et al., 2005). In this analysis it had the highest score on factor 1, at both scales analysed, and was strongly connected to harvest data and proportion annual crops but not to complexity metrics. A surprising result was that field size was represented by factor 1 at the 5 km scale and by almost equal scores on factors 1 and 3 at the 1 km scale. Field size is thus not related to other structural variables in a simple way, but is instead the variable connecting intensity and complexity at the 1 km scale.

Based on the reasoning above we propose that agricultural landscapes can indeed vary along more than the axis of intensity.

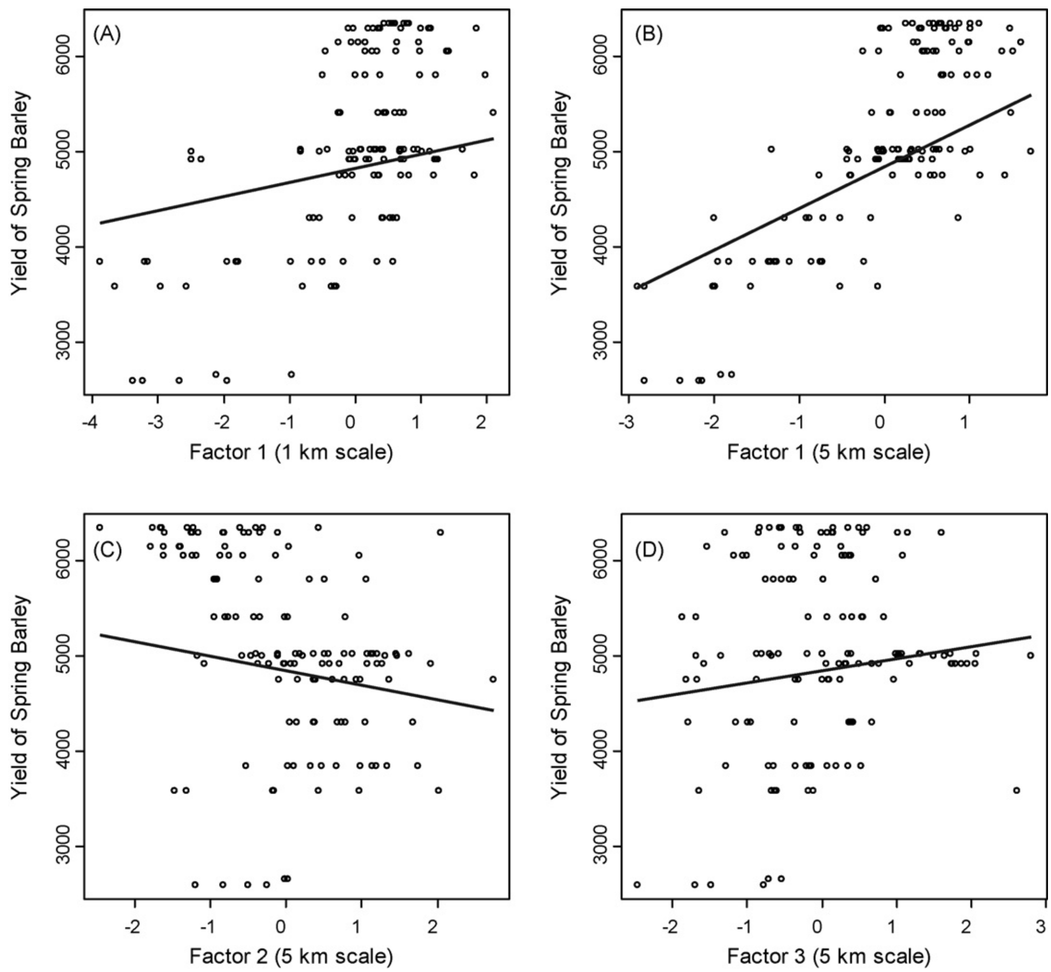

Fig. 2. The yield of spring barley (kg/ha) in relation to factors resulting from factor analysis. A is for the 1 km scale, and B, C, and D are for the 5 km scale.

This means that we cannot equate high intensity with low complexity but rather should look at these factors as two practically separate axes (see Fig. 3 for a conceptual picture), which has also been suggested by Firbank et al. (2008). We believe that the second component of landscape variation found here, complexity or structure, can be represented by the size, shape and distribution of land use units including small semi-natural habitats. Using PCA, similar results were found in central Spain (Concepción et al., 2007) and Brittany, France (Millán de la Peña et al., 2003), where the first components were interpreted as intensity related and the second ones as components of patch shape and natural vegetation or openness/connectivity respectively.

Based on the above we suggest that care should be taken to keep separate the concepts of land use intensity and landscape complexity. These are not the opposites of one another but important variation occurs in each of these dimensions independent of the other dimension.

4.2. The spatial scale of analysis

The division between land use intensity and landscape structure proved to be slightly less evident at the larger spatial scale, where proportion pasture and leys were represented together with structural variables in factors 2 and 3. This follows the reasoning by Purtauf et al. (2005), that general land use data are more closely correlated at larger spatial scales and are thus harder to split into separate axes and also that they tend to dominate over management related data. At this larger scale the

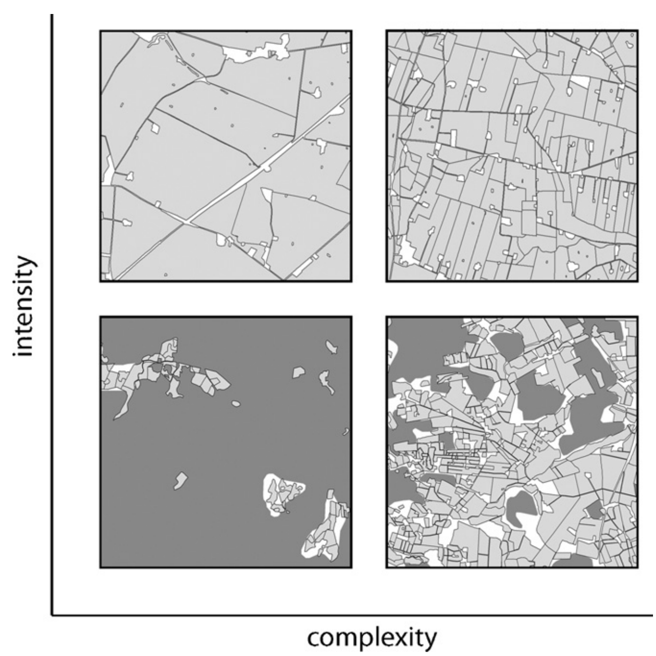

Fig. 3. A conceptual graph of how two of the factors from the analysis, representing intensity and complexity, can be visualised. As an example, four landscapes from the study area are placed in the graph to depict the landscape types indicated at the four positions respectively. Medium grey represents farmland and dark grey represents forest.

different components of structure are not as tightly connected, but are split between all three factors; factor 1 field size, factor 2 land use diversity and factor 3 field borders. The 1 km analysis gave a cleaner split of variables over factors and thus captured the variation in the dataset used here well, but it should be noted that field size was split between factors 2 and 3. The smaller scale makes possible a more detailed description of structure and complexity via variables built on field surveys and aerial photographs. Because of the labour intensity of field surveys and of digitising maps and aerial photographs, we do not have detailed information on small semi-natural habitats at the 5 km scale. We thus have to rely on field borders as a proxy. Despite this, field border was quite well separated from intensity (factor 1), even though that factor included field size. The agricultural landscape follows some large scale general patterns of intensity and land use, but there are many local exceptions leading to an uncoupling of these general patters, detectable at smaller spatial scales. If a study concerns organisms dependent on resources within 1 km one should be cautious about characterising the landscape by variables gathered at a larger scale. One should also be aware that any classification of a landscape made at a large spatial scale can be misleading on a local scale.

4.3. Indicators of farmland intensity and complexity

One aim of this study was to find general indicators of land use intensity and complexity. An already popular one, the proportion farmland in the landscape, was here represented in the first factor together with proportion of annual crops. Factor 1 was also highly correlated with the yield of spring barley, which indicates management intensity. We believe that both the proportion of total farmland per landscape and the proportion of annual crops are good indicators of land use intensity. These variables are also consistent over both spatial scales. The size of fields on the other hand, is not a robust measure of intensity since it was represented in both the intensity and structure related factors. This indicates that field size can either be regarded as a measure of intensity or a structurally related one. This would mean that using only field size as a landscape descriptor includes information on both intensity and complexity. The amount of field borders is a much better indicator of complexity. However, indices on land use diversity and structure (Simpson land use diversity and Contagion) were separated from small habitats and field borders and may be considered to be a different aspect of landscape complexity.

4.4. Landscape type and farming systems

From our results we can identify not only the intensity and complexity of landscapes, but also the landscapes shaped by different farming systems. The intensity factor was positively related to the proportion of annual crops. However, there are landscapes where pasture and leys are more dominating than annual crops. It is interesting to note that the proportion permanent pasture in the landscape was not simply the opposite of the intensity related first factor, something found in a PCA at a 10 km $\times$ 10 km scale study in Britain (Siriwardena et al., 2001). Instead, proportion pasture was a factor of its own, or in combination with leys and land use diversity depending on the spatial scale of analysis. This means that a landscape rich in pastures is not simply the opposite of an intensely farmed one, but an altogether different landscape type and direction of farming. The same is true for landscapes dominated by leys, which is mainly for cattle and dairy production. A similar result was found in Brittany, France, with one principal component describing the intensity of farming and another describing the openness of the landscape (Millán de la Peña et al., 2003). In that case the openness was also associated with maize used for milk production. This also follows the suggestion of Firbank et al. (2008), that agricultural landscapes can be described from crop management, structure and large scale land use. High production of annual crops (here represented by spring barley) was weakly positively associated with factor 3 representing complexity at the 5 km scale, while a high proportion of leys in the landscape was positively associated with field borders. This indicates that presence of border habitats is related to the direction of farming, in this case cattle and dairy, and could be interpreted such that intensification has different effects on the original landscape structure, depending on the farming system (Millán de la Peña et al., 2003). Recent studies in Sweden and England (Rundlöf and Smith, 2006; Gabriel et al., 2009) suggests that landscapes with a lower potential for high production farming are associated with a higher proportion of organic farming which is associated with low intensity management practices. The characteristics of the landscape thus influences the direction of farming (e.g. specialisation in plant or animal production) which in turn has an effect on further transformations of landscape structure and intensity of management.

Of course, it could be argued that pasture and leys might indicate intensity of beef or dairy production, i.e. a different kind of intensity than measured by yield of barley. To an extent, this could be true for leys, which are required for high dairy production. However, pastures as defined here are permanent, semi-natural habitats which are practically unfertilised. They are mostly not very productive and would in many cases probably be forested if it was not for the agri-environment schemes. It should also be noted that the yield of barley is estimated per hectare if it is grown, and not as the sum over an area. Thus, low barley yield mostly indicates low productivity of the land. At the 5 km scale, factor 2 that contained both leys and pasture was negatively associated with barley yield, which indicates this fact. In contrast, factor 3 that contained leys, but not pasture, was positively associated with barley yield. This probably indicates areas of high dairy production that does not rely on pastures.

Historically, cattle husbandry and the creation of pastures seem to follow different local patterns than do crop production. Pastures were often found on stony, too wet or otherwise unproductive land not suitable for crop production (Emanuelsson et al., 1985). Today some of these old pastures are still grazed although a substantial part of them were planted with trees during the 19th and 20th centuries. During the same period dry and stony meadows were transformed into pastures while moist meadows were drained and turned into leys or crop fields (Emanuelsson et al., 1985).

Scania has a mixed geology, with different soil textures ranging from sand to clay. Most common is glacial soil with clayey till dominating in the southwest and sandy till in the northeast. In the most productive areas of Scania the naturally fertile soils and the early introduction of artificial fertilisers made animal husbandry, pastures and meadows unprofitable in relation to cereal crop production and today these areas almost completely lack meadows and most also lack pastures (Emanuelsson et al., 1985). Areas still rich in pastures are mostly those that lie on soils of fairly low fertility. This is similar to the results of Gabriel et al. (2009).

The diversity of crops was positively related to intensity (factor 1) and to field size at both spatial scales, i.e. the larger the proportion of farmed land, fields and harvests are, the higher was crop diversity. This does not follow the general impression of a more complex landscape also hosting a diverse array of crops. The reason for this could be that also where fields and farms are smaller, today's farmers use the same common crops as in intensely farmed areas and the only pattern visible is the one where more farmland within the investigated area makes more different crops possible.

Our study is conducted in a rather small area with highly variable agriculture, which partly reflects the variable natural conditions. Our conclusions, that farming intensity and complexity are independent, are in line with several other recent studies (Millán de la Peña et al., 2003; Concepción et al., 2007; Firbank et al., 2008) and we expect them to be quite general. However, this deserves to be verified by studies from other parts of the world and across larger geographic and geological gradients.

4.5. Summary and conclusions

From the factor analyses we concluded that there were indeed several different and unrelated components to be extracted from landscape and agricultural data. We suggest that the most important ones be interpreted as farming intensity and landscape complexity, and also farming direction. Intensity can be represented by harvest data or proportion of farmland or annual crops; the latter being easy to calculate with access to spatially explicit agricultural statistics. Complexity can be well represented by land use diversity and amount of field borders, and small semi-natural habitats. To describe complexity we have used detailed information (at the level of that available from aerial photographs) but more easily available data, e.g. the length of field borders, is also valuable.

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