Identifying High Nature Value farmlands on a national scale based on multivariate typology at municipality (LAU 2) level

Wiesław Mądry[1], Marcin Olik[1], Barbara Roszkowska-Mądra[2], Marcin Studnicki[1], Dariusz Gozdowski[1], Elżbieta Wójcik-Gront[1]

[1]Department of Experimental Design and Bioinformatics, Faculty of Agriculture and Biology, Warsaw University of Life Sciences – SGGW, Poland, e-mail: elzbieta_wojcik_gront@sggw.pl
[2]Department of Entrepreneurship, Faculty of Economics and Management, University of Białystok, Poland

SUMMARY

High Nature Value farmlands in Europe are of greatest importance in the conservation of biodiversity. Their environmental importance has been recognized for some time, and has been studied mostly in Western Europe. This article describes the results of multivariate statistical analyses performed on data (13 variables) collected from the latest National Agricultural Census and the CORINE database to provide a typology of farmlands with respect to their nature value at municipality level (LAU 2, Local Administrative Units level 2) across Poland. All municipalities were grouped into eight categories (types). Some of the farmland categories were considered to be High Nature Value farmland (HNVf). The following interrelated variables mostly contributed to the identification of HNVf: share of protected areas and forest, grassland, arable land and fallow, farmland cover diversity, and rate of nitrogen fertilization. HNVf was identified in 958 out of 2173 municipalities, covering 44% of the territory of Poland. The identified HNVf also overlaps partially (61%) with LFAs (Less Favored Areas). Farmlands with the highest nature value are located mostly across mountain and hilly areas, close to forests, and protected areas on lowlands and river valleys. The identified HNV farmlands are characterized by low-input farming systems and a large share of semi-natural habitats with a high landscape mosaic.

Keywords: agricultural intensity, farmland typology, landscape ecology, less favored areas, mapping farming types, multivariate analysis

1. Introduction

Farmlands (also called agricultural areas or agricultural land, defined as including Utilizable Agricultural Areas—UAA—and agricultural-ecological wasteland

including rough terrain, shrubs, scrubs, peatlands, wetlands, streams, etc.) provide varied habitats for many wild plants and animals. Biodiversity on farmlands has been declining throughout Europe as a result of intensification of agriculture and abandonment of marginal lands since the second half of the 20th century (Keenleyside et al. 2014; Lomba et al. 2014; Benedetti 2017). Due to increasing awareness regarding the declining biodiversity on farmlands, the term High Nature Value farmland (HNVf) has become established (Beaufoy et al. 1994; Andersen et al. 2003). Typical HNVfs are "those areas in Europe where agriculture is a major (usually the dominant) land use and where that agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both" (Andersen et al. 2003). Thus, HNVf comprises not only the physical farmland that can maintain the biodiversity of plant and animal species and their habitats, but also the accompanying High Nature Value farming system (Paracchini et al. 2008; Strohbach et al. 2015). HNV farming systems support the existence of agriculture-dependent species and their habitat, as they are low-intensity farming systems (Lomba et al. 2014, 2015, 2017). HNVf is characterized based on the proportion of semi-natural vegetation and the extent of permanently or periodically uncultivated landscape elements in farmland; the density of livestock; and the input of nutrients, agrochemicals, and irrigation in cropping systems (Andersen et al. 2003; Lomba et al. 2014; Benedetti 2017). Andersen et al. (2003) defined three types of HNV farmland, and this categorization has been commonly followed. With subsequent modifications (Paracchini et al. 2008; Lomba et al. 2014) they are as follows: Type 1 – farmlands under low-intensity management with a high proportion of semi-natural vegetation such as extensive permanent grassland, forest, scrub, etc.; Type 2 – farmlands dominated by low-intensity farming systems and with a lower proportion of semi-natural vegetation, mosaics (high diversity) of semi-natural and cultivated lands, and presence of landscape elements such as patches of forests and shrubs, field margins, streams, etc.; Type 3 – farmlands supporting rare species or a high proportion of European or world populations. In practice, the three HNVf types can overlap—this

concerns mainly types 1 and 2—making implementation at different spatial scales difficult (Peppiette et al. 2012; Lomba et al. 2014). In Europe, HNVf is estimated to account for ca. 30% of the total area taken up by farmland, with very different shares among the members of the European Union (EU). The largest share of HNVfs is present in Eastern and Southern Europe, especially in mountains and highland areas (EEA 2004; Keenleyside et al. 2014; Oppermann et al. 2012). HNVfs are most widespread in areas where agricultural production or activity is more difficult because of such factors as low soil fertility, harsh climatic conditions, and steep slopes in mountain areas (Keenleyside et al. 2014; Paracchini et al. 2008).

Identification of HNV farmlands serves chiefly to 1) map the occurrence and distribution of such farmland for appropriate targeting of conservation measures and supporting associated rural communities, and 2) control the impact of humans on the environment, for example by the exclusion of High Nature Value farming areas from intensive agricultural management areas (Andersen et al. 2003; Keenleyside et al. 2014; Lomba et al. 2015; Strohbach et al. 2015; Teillard et al. 2012). Efforts have been initiated to develop approaches and indicators to identify HNVf, mostly in Western Europe, using different methods (Kikas et al. 2018; Brunbjerg et al. 2016; Lomba et al. 2014, 2015; van Doorn and Elbersen 2012). However, most of the methods used in HNVf studies to date have the aim of obtaining one indicator which shows whether or not farmland is of HNVf type (Lomba et al. 2014; Paracchini et al. 2008; Peppiette et al. 2012; Ribeiro et al. 2014). These methods are developed based on the relationships of nature value characteristics, investigated beforehand, which then are adopted *a priori* in obtaining the indicator. However, multivariate statistical analyses should deliver better knowledge on the nature value of farmland, its aggregation and regional distribution, and reveal interrelationships between the analyzed characteristics which are assumed to contribute to farmland nature value (Sutkowska et al. 2013; Lomba et al. 2014; Kikas et al. 2018). When identifying HNVf areas, the EU recommends including data on land cover, farming systems, and diversity of wild

plant and animal species at farm or administrative unit level (Paracchini et al. 2008; Keenleyside et al. 2014; Brunbjerg et al. 2016; Lomba et al. 2014, 2017).

Across Poland, as in other European countries, farms fall somewhere on a continuum from intensive, highly productive farms with low biodiversity to extensive, low-productive, high-biodiversity HNVfs (Castel et al. 2010; Sutkowska et al. 2013; Lomba et al. 2014). In Poland, agricultural intensity is strongly positively correlated with farm size (Castel et al. 2010). Particularly the southern and eastern parts of Poland are characterized by small farms and low-intensity farming, in contrast to the intensive farming systems in central and western Poland (Keenleyside et al. 2014). Grazed extensive grassland and wetlands, such as the Biebrza River Valley, Masuria Lakeland, Warta and Noteć River Valley, and Pomeranian Lakeland, are nesting habitats of rare and threatened bird species. A high biodiversity of flora and fauna, including areas with threatened species, is common in the Carpathian and Swietokrzyskie Mountains. The decline in livestock numbers in the past 25 years, related to deep economic transformations, has led to the abandonment of important pastoral habitats and a consequent loss of valuable species. This has happened in the limestone grasslands of the Kraków-Częstochowa Uplands and also in the permanent grasslands in the Carpathian Mountains (Musiał 2007).

To date, only preliminary mapping of HNVf across Poland has been performed by the National Institute of Geodesy and Cartography (Oppermann et al. 2012; Keenleyside et al. 2014). Hence, within this study, the aim is to:

• identify and map HNV farmlands for the whole of Poland at municipality level (LAU 2: level 2 of Local Administrative Units according to Eurostat).

• implement a multivariate methodological approach providing information on the likely occurrence and distribution of HNV farmland that is based on available current information on the high nature value of farmland at municipality level.

• assess whether the identified HNVfs lie partially within agricultural areas with various handicaps (low soil fertility, harsh climate, shortage of precipitation, short cropping season, mountainous or hilly landscapes, tendencies towards depopulation) known as Less Favored Areas (LFAs).

2. Materials and methods

2.1. Data used

In the studies two groups of characteristics (variables) were used. Variables in the first group describe farming systems, and those in the other group characterize land cover. To describe the nature and potential of farming systems existing in Poland, the data collected from the National Agricultural Census carried out in 2010 by the Polish Central Statistical Office (GUS) was analyzed. This is the only complete and current database that characterizes agriculture across the whole country at LAU 2 level (formerly NUTS level 5: municipalities or communes). The data on individual farms was aggregated to the municipality level during collection, and therefore only the aggregated data is available. The data regarding each municipality was found to be complete; therefore, the authors did not assume any uncertainty. The primary disadvantage of the data used in this study is the aggregation performed at the municipality level, which does not permit investigation of HNVf diversification within a municipality. The data contains information on the structure and size of farmland in the municipality area, livestock numbers, level of nitrogen (N) fertilization, and some aspects of the resources and socioeconomic condition of farms in Poland (Table 1). The data on farms was supplemented with data on vegetation from the European inventory of land cover—the CORINE database (Coordination of Information on the Environment)—from 2012 (this is based on data from a similar period as the census) and with data on protected areas, representing proxies for the biodiversity in each municipality.

General information about farmland cover (farm landscape) diversity was included in the form of the Shannon diversity index (Shannon 1948) calculated from the shares of all forms of Farmland cover by the formula:

$$H = \sum_{i=1}^{n} p_i \, ln \, p_i$$

where p_i is the share of the i-th form of Farmland cover. Similarly, crop diversity was calculated from the shares of all crops in the arable area.

Table 1. Characteristics and statistical description of the 13 variables collected at LAU 2 level which are used in the analysis (abbreviations are explained below the table)

No	Variable	Definition
1	Forest area in MA [%]	Total forest area divided by total (land) municipality area (MA)
2	UAA in Farmland [%]	Total Utilizable Agricultural Area (UAA) divided by Farmland area
3	Wastelands in MA [%]	Total wastelands and ecological uses area divided by MA
4	Grassland in Farmland [%]	Total grasslands (meadows and pastures) area divided by Farmland area
5	AA in Farmland [%]	Total Arable Area (AA) divided by Farmland area
6	Fallow area in Farmland [%]	Total fallows area divided by Farmland area
7	Protected area in MA [%]	Total area under all types of nature protection (national parks, landscape parks and nature reserves) divided by MA
8	Farmland cover diversity (FCD) [Shannon FCD Index]	Shannon diversity index calculated based on all farmland cover categories specified in NAC 2010 (AA, fallows, orchards, home gardens, grasslands, forests and shrubs on farms)
9	Crop diversity (CD) [Shannon CD Index]	Shannon diversity index calculated based on all crops grown on AA specified in NAC 2010
10	Farm area [ha]	Total farmland area divided by total number of farms
11	Livestock density per UAA [LU/ha]	Number of livestock (expressed in Large Livestock Units) divided by UAA
12	Nitrogen per UAA [kg/ha]	Summarized nitrogen fertilization (in kg of pure nitrogen) divided by UAA
13	Orchard area in Farmland [%]	Total orchard area (fruit trees and other fruit crops) divided by Farmland area

| No	Origin	Min	Max	Mean	CV%	Moran's I Coefficient
1	CORINE	0	79.6	26.1	65.0	**0.278**
2	CORINE	16.0	96.5	64.9	27.1	**0.221**
3	CORINE	0	29.9	1.4	127.9	**0.232**
4	NAC2010	1.1	91.3	23.0	71.9	**0.404**
5	NAC2010	0.7	95.0	64.9	34.0	**0.331**
6	NAC2010	0	59.5	3.4	142.4	**0.271**
7	Nature protection database CSOP	0	100	31.3	104.8	**0.345**
8	NAC2010	0.83	1.76	1.29	14.2	**0.146**
9	NAC2010	2.12	5.24	4.14	11.7	**0.088**
10	NAC2010	0.7	63.8	10.7	74.9	**0.386**
11	NAC2010	0.01	2.19	0.60	63.8	**0.288**
12	NAC2010	0	158.1	60.4	53.4	**0.379**
13	**NAC2010**	**0**	**30.2**	**1.9**	**191.6**	**0.388**

MA – municipality area; UAA – Utilizable Agricultural Area; AA – arable area; CV% – coefficient of variation; CORINE – CORINE database; NAC 2010 – Data from National Agricultural Census 2010 carried out by the Central Statistical Office of Poland (CSOP, entered March 2016).

Based on this information, 13 characteristics (Table 1) were constructed to describe the nature value of farmland in each municipality. The characteristics were selected based on their importance in performing potential assessment of HNVf following the examples provided in similar studies (Oppermann et al. 2012; Keenleyside et al. 2014; Lomba et al. 2014; Strohbach et al. 2015). Table 1 presents the rationale behind these characteristics.

3.   Statistical analysis

To perform the analysis, the 13 variables described in Table 1 regarding 2173 rural and rural-urban municipalities were used. First, the frequency distribution of each variable within all the municipalities was analyzed using the normal probability plot technique (Z-score scaling). The distribution of some variables turned out to have many values that were very distant from the mean for all of the municipalities. Such cases are considered as outliers, and were excluded from further multivariate analyses based on a qq-plot for each variable according to the methodology proposed by Wilk and Gnadeskian (Pecher et al. 2013; Wilk and Gnanadesikan 1968). This decision resulted from the need to ensure reliability of inference, using in this study statistical methods which require normality of the distribution. On the other hand, outlier municipalities can be identified and/or interpreted as indicating their assignment to non-HNVf. Analysis of characteristics related to agricultural land use and agricultural intensity indicating non-HNVf (e.g. low share of farmland in the municipality area, high nitrogen input and/or high livestock density) made it possible to exclude 68 municipalities. Among them, 14 entries had a very low share of farmland in the municipality area (<10%) and thus a very high share of forest (municipality group O1). This group of municipalities was assumed to include HNVf, although the available data was not sufficient to properly assess the nature value of these agro-ecosystems. These municipalities were considered to be typical forest areas, not generally displaying farmland attributes. Furthermore, 54 entries with high farming intensity were qualified as non-HNVf (municipality group O2). In addition, there were

municipalities with exceptionally high shares of conventional (market and intensive) orchards. In Poland, market orchards are concentrated in several relatively small regions. In 91% of the municipalities the share of orchards in farmland was found to be less than 5%, and there are few municipalities where orchards constitute more than 50% of agricultural area. Thus, in the studies on HNVf identification, the share of orchards in the farmland area was treated as subject to a cutoff. The frequency distribution of the share of orchards in the farmland area was investigated across all of the municipalities, and those of them with a share of orchards higher than 30% were excluded from the analyzed data set (municipality group O3, considered as non-HNVf). Through these procedures, 95 outlying municipalities were identified. Table 2 presents a detailed description of the excluded municipalities, and Figures 1 and 2 show their graphical representation.
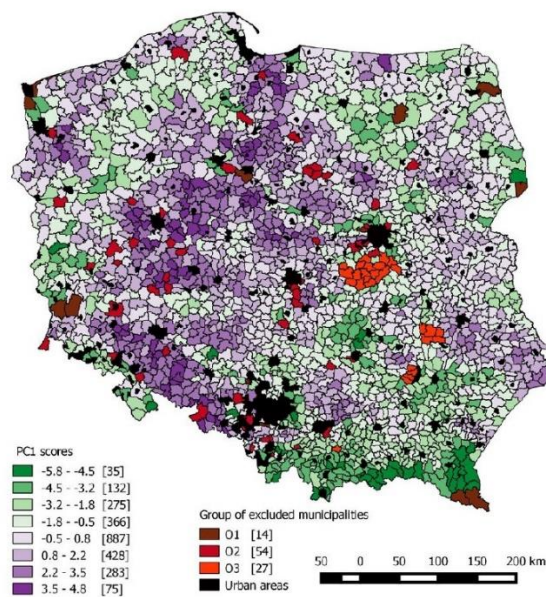
Figure 1. Spatial distribution of the 2078 municipalities across Poland according to PC1 scores representing approximate condensed information about the nature value of these farmland units (numbers of units assigned to the particular intervals of PC1 scores or to groups O1, O2 and O3 of the outliers are shown in brackets; the smaller the PC1 score for a municipality, the higher the nature value of its farmland)

Table 2. Means of the variables in each of 8 separated clusters and in each of 3
excluded groups of municipalities and PC1 scores for the considered groups
(abbreviations are explained in Table 1)

| No	Variable	Excluded LAU 2[2]		
		O1	O2	O3
1	Forest area in MA [%]	72.0	22.7	14.9
2	UAA in MA [%]	8.7	62.2	77.6
3	Wastelands in MA [%]	2.7	1.2	0.7
4	Grassland in Farmland [%][1]	38.3	21.4	9.1
5	AA in Farmland [%]	18.4	66.9	21.9
6	Fallow area in Farmland [%]	6.7	2.8	7.0
7	Protected area in MA [%]	44.9	26.0	28.7
8	Farmland cover diversity (FCD) [Shannon FCD Index]	NA[3]	1.25	1.62
9	Crop diversity (CD) [Shannon CD Index]	NA[3]	3.67	4.13
10	Farm area [ha]	20.04	14.75	5.79
11	Livestock density per UAA [LU/ha]	0.24	2.10	0.15
12	Nitrogen per UAA [kg/ha]	7.65	70.92	42.56
13	Orchard area in Farmland [%]	0.3	0.8	57.1
A	PC1 score			
B	Nearest neighbor ratio			
C	Number of municipalities in the group and its frequency (%) among all municipalities (in parentheses)	14 (0.6)	54 (2.5)	27 (1.2)

No	LAU 2 group/Farmland category excluding 95 municipalities								
	1	2	3	4	5	6	7	8	All
1	47.2	34.8	30.5	28.3	23.1	21.4	16.8	15.1	26.1
2	43.4	55.0	60.0	62.3	68.4	70.1	74.7	76.1	64.9
3	0.9	1.2	1.0	1.8	1.3	1.6	1.3	1.4	1.4
4	52.9	37.3	27.3	25.0	18.5	15.4	11.3	8.9	23.0
5	17.7	39.7	53.7	63.0	72.2	79.0	85.0	87.6	64.9
6	4.4	6.1	5.7	3.7	2.9	1.8	1.1	1.1	3.4
7	66.0	41.2	41.2	32.1	28.1	23.4	18.6	16.4	31.3
8	1.40	1.48	1.46	1.36	1.29	1.18	1.09	1.04	1.29
9	4.11	4.13	4.16	4.15	4.15	4.15	4.10	4.16	4.14
10	4.08	6.26	5.46	11.88	9.27	14.14	13.95	20.79	10.70
11	0.38	0.44	0.50	0.58	0.69	0.69	0.77	0.61	0.60
12	5.09	20.17	35.58	48.09	65.80	82.90	99.23	120.34	60.45
13	1.0	2.3	2.6	2.2	2.4	1.4	0.8	0.7	1.9
A	-3.80	-2.40	-1.49	-0.46	0.47	1.39	2.26	2.92	0.00
B	0.638	0.944	0.864	0.915	0.812	0.777	0.810	0.754	
C	105 (4.8)	304 (14.0)	216 (9.9)	319 (14.7)	452 (20.8)	311 (14.3)	201 (9.4)	170 (7.8)	2078 (95.7)

[1] Grassland area is the total area of permanent grassland

[2] O1, O2 and O3 denote the groups of excluded LAU 2 units

[3] NA – FCD and CD Indices were not calculated due to the unavailability of data for proportions of some land or crop categories in LAU 2 units assigned to O1.
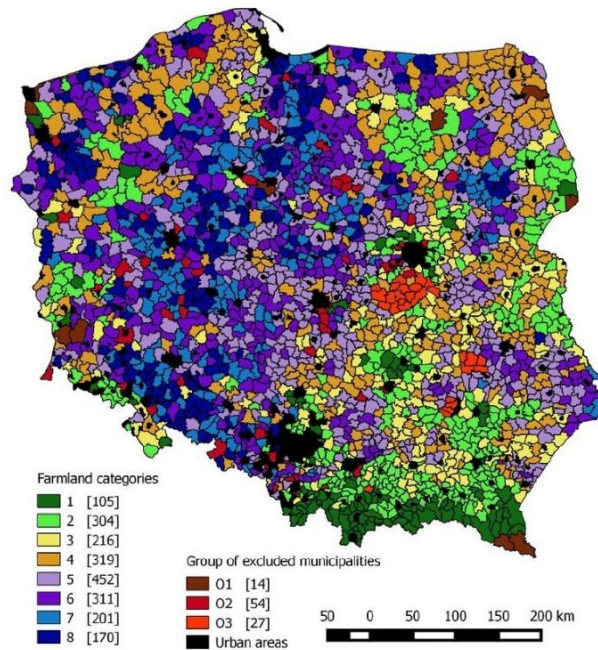
Figure 2. Spatial distribution of eight categories of farmland of municipalities across Poland as identified in cluster analysis carried out for 2078 units on the basis of the 13 characteristics describing the nature value of farmland, and three specific groups of excluded municipalities (O1, O2 and O3) (the farmland categories were sorted by gradient of PC1, indicating the nature value of farmland, being also an HNVf indicator); the category 1, 2 and 3 farmlands were recognized as HNV farmland type 1 and 2, and category 4 as potential HNVf type 2 or type 3; numbers of units in each group are shown in brackets)

Second, studies of diversity and typology among the remaining 2078 municipalities were performed using principal component analysis (PCA) and cluster analysis (Castel et al. 2010; Pecher et al. 2013; Ribeiro et al. 2014). These procedures are considered to be very effective to perform numerical taxonomy of multivariate entries like farms or area units (Mądry et al. 2013). In this study PCA identifies original variables that are meaningful in the discrimination of municipalities' farmlands according to the nature value of farming systems in each municipality. The set of 13 characteristics was analyzed using PCA as described by Pecher et al. (2013). The PCA results were subsequently employed in a hierarchical clustering approach using the Ward algorithm with squared

Euclidean distance for the 13 standardized variables, to classify the municipalities into homogeneous groups with relatively equal size. The optimal number of clusters was determined based on two criteria: the pseudo-F statistic and pseudo-t2 statistic. Through these analyses, several groups of municipalities were distinguished, each of them specifying a farmland category/type. Some of the farmland categories were identified to be HNVf or potential HNVf. PCA and cluster analysis were performed using SAS 10 software (SAS 2012). Maps showing areas of municipalities with PC1 scores and maps presenting the groups identified via cluster analysis were prepared using QGIS 2.1 software (Figures 1 and 2).

The degree to which one municipality is similar to other nearby municipalities was also assessed. In the case of spatial pattern analysis, Moran's I spatial autocorrelation coefficient was calculated for all characteristics (Table 1) and the nearest neighbor ratio was calculated (Mitchel 2005) for each of the municipality groups distinguished by the cluster analysis (Table 2) to estimate the spatial clustering of the groups. The nearest neighbor ratio (NNR) is a parameter calculated as observed mean distance/expected mean distance. Smaller values indicate greater concentration of geographical objects (in this case municipalities), while higher values indicate greater dispersion of the objects. The spatial analyses were performed using ArcGIS 9.3 software.

The obtained typology represents categories of farmland in terms of the nature value of their farming system. This provides a basis to recognize HNVf and to create a map of HNVf and non-HNVf at municipality level. Moreover, the recognized HNVf can be categorized according to the types suggested by Andersen et al. (2003).

In addition, to check the most common hypothesis concerning consistency between the spatial extent of HNVf and less favored areas (LFAs) (areas with natural handicaps to agricultural intensification in Poland, identified by the Ministry of Agriculture and Rural Development and supported by EU subsidies), four groups of municipalities were formed and mapped: "HNVf and LFA," "HNVf but non-LFA," "non-HNVf but LFA," and "non-HNVf and non-LFA."

4.   Results and discussion

4.1. Descriptive statistics for the municipalities

On average, 26% of Poland's area was covered by forests, and 65% by farmlands. The farmland was dominated by arable land, mainly with cereals (mean=65%), followed by permanent grassland (mean=23%), fallow (mean=3%), and orchard (mean=2%). The average Polish farm area at municipality level was equal to ca. 11 ha, with average nitrogen fertilization of 60 kg/ha and average livestock density (mostly cattle and pigs) of 0.60 head of livestock/ha of farmland. However, municipalities were very diverse in terms of land cover structure indicators, with respect to both the total area of the municipality and its farmland (the coefficient of variation—CV—was found to range from 27% to 142%; Table 1), and in terms of farming system intensity indicators (CV=53–192%). The CV of municipalities' farm areas was found to be 75%, showing a great variation in landscape elements. These findings illustrate the high diversity of farmland nature value at municipality level in Poland. This justifies the use of a typology of farmlands based upon these administrative units to search for and identify HNVf. While the CV of farmland cover diversity and crop diversity was not high (14% and 12% respectively), this is mainly due to the use of aggregated data on land cover to calculate values of the Shannon diversity indices. For all analyzed characteristics, significant (P<0.001) positive spatial autocorrelation was found, which means that neighboring municipalities have similar values of these characteristics. The strongest autocorrelation was found in case of the following characteristics: farm area, grassland area, and share of orchard area in farmland.

4.2. Characteristics contributing most to the identification of HNVf

Based on the elbow criterion, only the first principal component (PC1) describes variation of all the original characteristics more than a single original characteristic (eigenvalue 4.42). It accounts for 34.6% of the total variability between municipalities (Figure 3). PC1 is mostly related to the proportion of different land types within both the whole municipality area and farmland, land cover diversity,
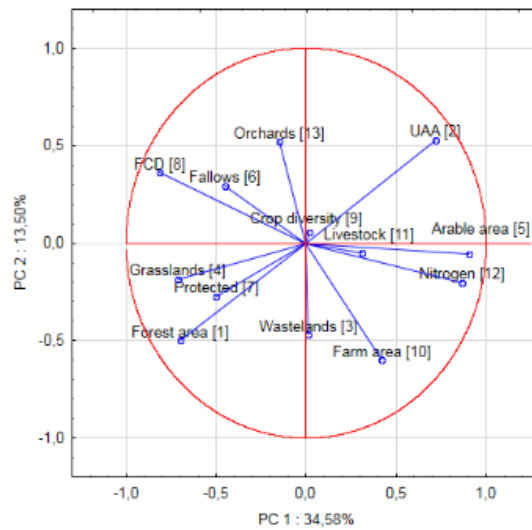
Figure 3. The original 13 variables projected onto the first two principal components (PC). The names of variables are abbreviated. Numbers in brackets correspond to the numbers of the variables in Table 1

and the amount of nitrogen. PC1 represents a major driver in establishing the nature value of farmlands at municipality level across Poland. The interrelated characteristics, substantially correlated with PC1, are the most meaningful in the discrimination of municipalities across Poland according to the nature value of their farmlands. These interrelated indicators of HNVf are as follows: share of protected areas, forest and farmland in the municipality area, share of grassland, arable area and fallow in farmland, and farmland cover diversity and nitrogen input. Therefore, PC1 scores provide condensed information about the nature value of these farmland units. If the PC1 score is higher, it means that the farmland's nature value is lower. Figure 3 shows a map of municipalities distributed according to their PC1 scores. The share of orchards in farmland and the share of fallow in the municipality area correlate with the second principal component PC2, which describes 13.5% of the total diversity. In addition, crop diversity does not correlate with either PC1 or PC2. In this research, farm size and livestock density were found to be weakly correlated with PC1, although in

other studies (Andersen et al. 2003; Lomba et al. 2014; Paracchini et al. 2008) livestock density has been considered to be an important indicator of HNVf. One reason for this difference may be the exclusion of 25 outlying municipalities due to their high livestock density.

4.3. Typology of municipalities' farmland based on cluster analysis

In the hierarchical cluster analysis, eight homogeneous groups of municipalities (without the excluded ones) were identified according to the pseudo-F and pseudo-t2 statistics. The optimal number of clusters was indicated by the highest value of the pseudo-F statistic and a low value of the pseudo-t2 statistic. Table 2 profiles these groups with the three excluded ones (O1, O2 and O3) by presenting the group-means for each of the characteristics. The first four groups (1–4) and O1 were qualified as HNVf. Groups 5–8, O2 and O3 were specified as non-HNVf.

The nearest neighbor ratio for all groups was found to be less than 1, which means that the spatial distribution of the distinguished groups (clusters) was not random. This confirms the cluster analysis results presented in Figure 2. The strongest spatial clustering was observed for groups 1 and 8 (hotspots of municipalities for these groups were observed), whereas for group 2 the spatial pattern was most random.

4.4. Detailed characterization of the four categories of farmlands recognized as HNVf

Category 1 farmland was characterized mainly by small size with a very low-intensity crop and grazed livestock farming system, a very high proportion of semi-natural permanent grassland and other semi-natural areas such as farmer's forest and shrubs, as well as high diversity of land cover. A major proportion of these mountain areas have large slopes, poor soil and harsh climate, where traditional, low-intensity farming has been established for a long time. This category of farmland has nature value features similar to HNVf type 1 according to Andersen et al. (2003), but they coexist with high landscape mosaic (a feature

of HNVf type 2). The combination of extensive agriculture with very small farms is rather unusual in Western Europe. It raises concerns about the economic profitability and stability of this kind of agriculture. This type of farmland was identified in 105 municipalities, accounting for 4.8% of the total number of municipalities across Poland. Most municipalities from this group are spatially distributed across southern Poland in the Carpathian and Swietokrzyskie Mountains (Figure 2). The majority of them are located near to national and landscape parks or other nature reserves. Some of the category 1 HNVfs are also scattered across Kampinoska Forest and the Kraków-Częstochowa Uplands, and also form isolated units within Bialowieza Forest, the Sandomierz Basin, and the Warta and Noteć River Valley. Regarding the maintenance and support of agro-biodiversity in Poland, category 1 HNVf is the most important. This is due to the high proportion of semi-natural vegetation, a mosaic of land cover, significant presence of landscape elements, and low-input farming, mainly cattle and sheep grazing.

Farmland in the second category exhibits features mainly of HNVf type 2 according to Andersen et al. (2003) and Lomba et al. (2014). It is characterized by small-sized, low-intensity, mixed, mostly crop and grazed livestock farming systems with a high proportion of semi-natural vegetation. This group has the highest farmland cover diversity index among the eight municipality groups, reflecting the presence of many landscape elements. The group includes 304 municipalities, 14.0% of the total number.

Category 2 HNVfs are spatially distributed across different regions of the country. Most of them are located across the south and south-east of Poland within the Carpathian and Swietokrzyskie Mountains (next to farmland areas of type 1), in the central Sandomierz Valley, and across eastern and northeastern lowland Poland within Lubelszczyzna, the Masuria Lakeland, the Narew and Supraśl River Valley, and Bialowieza Forest (Figure 2). Moreover, this kind of HNVf forms patches across lowland areas within the Zielona Góra region (Rzepinska Forest), Kampinoska Forest, Warta and Noteć River Valley,

Pomeranian Lakeland, Sudety Mountains and Kraków-Częstochowa Uplands. In general, this category of HNVfs partially overlaps with some protected areas.

As farm size does not provide enough information to discriminate between HNVf types 1 and 2, a strong correlation between farm size and farming intensity allows one to assert only the dominance of attributes of one HNVf type over the other in the analyzed areas. HNVf type 2 includes farmlands more often intensively managed than the semi-natural HNVf type 1. In practice, HNVf type 1 and type 2 can overlap, making implementation at different spatial scales difficult (Peppiette et al. 2012; Lomba et al. 2014).

Category 3 farmland is similar to the category 2 farmland identified in this analysis. It is characterized by a lower proportion of semi-natural vegetation in comparison with category 2, but with a significant mosaic of agricultural landscape and extensive mixed crop-livestock farming systems. In general, category 3 farmland may be regarded as HNVf type 2 according to Andersen et al. (2003) and Lomba et al. (2014). It is found in 216 municipalities, which is 9.9% of the total. It is located mainly in southeastern and eastern Poland, and is accompanied by category 2 HNVfs, sometimes filling spaces between HNVfs of categories 2 and 4 (Figure 2).

Category 4 farmland is the most prevalent among the four farmland categories qualified as HNVf. It is located in the 319 municipalities in group 4, comprising 14.7% of the total number of municipalities. It is distributed across different regions of Poland, overlapping with nine national parks and several landscape parks and reserves (Figure 2). Municipalities classified as category 4 are divided into two subgroups. Farmland in municipalities belonging to the first of the two subgroups can be recognized as potential HNVf type 2, where moderately intensive inputs and larger farm areas are associated with a mosaic of semi-natural and cultivated land (Lomba et al. 2014). It is located in central, eastern and southeastern Poland, chiefly adjacent to category 2 and 3 HNVfs and also non-HNVf areas. Therefore, this category of HNVf may also be considered a transition zone between HNVfs and non-HNVfs. However, intensive arable farming is possible in some of these areas, due to a relatively flat landscape and
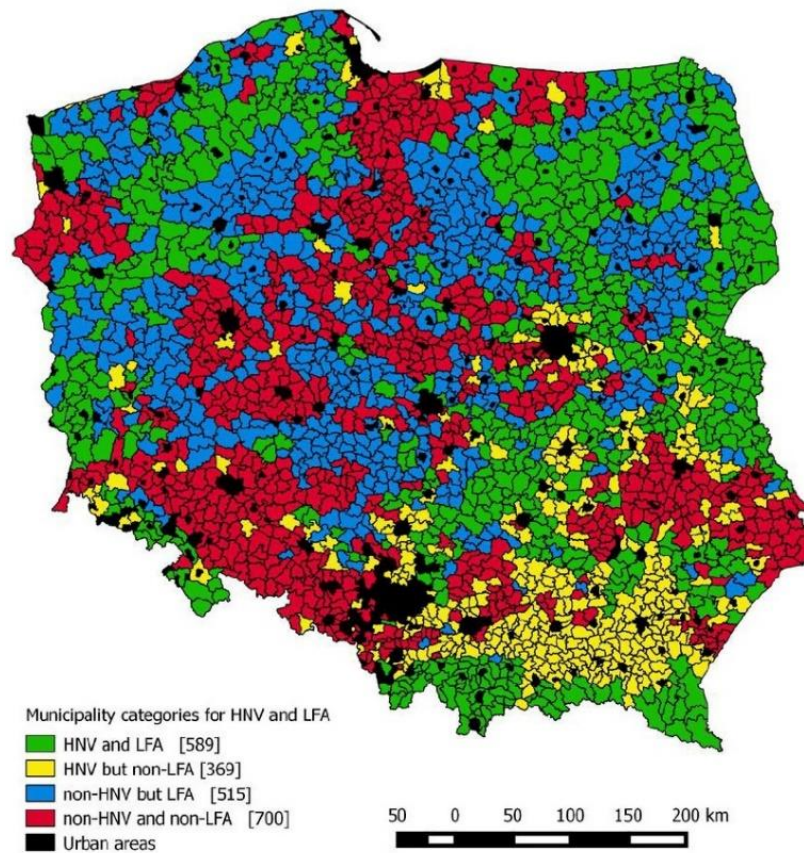
fertile soil. Municipalities belonging to the second subgroup are located in northern Poland, creating two distinct patches in the west and east. These patches overlap the young glacial lakeland landscape, with strong undulation of land and a mosaic of soil fertility. Some of them are located within the Biebrza River Valley, Narew River Valley, Masuria and Suwalki-Augustow Lakelands (northeastern Poland), Warta and Noteć River Valley and Pomeranian Lakeland (northwestern Poland). Farmlands in categories 1–4 are considered to have High Nature Value. Thus, these farmlands should be protected by excluding them from intensive farming. This can be achieved by directing European and local subsidies to these regions to support the maintenance of low-intensity agriculture.

The remaining categories of farmland were classified as non-HNVfs, and are characterized by a low (category 5) to extremely low (category 8) proportion of semi-natural vegetation, few or very few landscape elements, moderate to very low land cover diversity (uniform agricultural landscape), intensively or highly intensively managed livestock and/or mixed farming systems, accompanied by moderate to very low cover of public forests and protected areas. These areas may be used for future agricultural intensification based on local and national requirements.

4.5. Relations between HNVf and LFA

The comparison of HNVf municipalities, identified in this study as groups 1, 2, 3, and 4 (Table 2) via cluster analysis, with the municipalities qualified in Poland as LFAs shows that they overlap to a degree of 61% (Figure 4). Regions identified as HNVf and LFAs include mainly Podlasie (northeastern Poland), Masuria and Suwalki-Augustow Lakelands (northeastern Poland), the Pomeranian Lakeland (northwestern Poland), the Carpathian and Swietokrzyskie Mountains (southern Poland), and the Bug and Narew River Valleys (eastern Poland). These regions are distinctive due to their poor soil fertility, harsh climate and cultivation handicaps (slope areas), and traditionally small-scale extensive agriculture. Support for these areas should be aimed at maintaining their present condition and preventing the degradation and abandonment of farmland.

Municipality categories for HNV and LFA

- 🟩 HNV and LFA [589]
- 🟨 HNV but non-LFA [369]
- 🟦 non-HNV but LFA [515]
- 🟥 non-HNV and non-LFA [700]
- ⬛ Urban areas

Figure 4. Spatial relation between the HNVf identified in the study and LFAs established officially in Poland; numbers of units in each category are shown in brackets

There is a large share of HNVf in non-LFAs, which corresponds to extensive, small-farm agriculture established in areas with a potential for high agricultural production. Most of the High Nature Value but non-LFA municipalities are located in the southeast of Poland in the Sandomierz Basin (marked in yellow in Figure 4), where HNVf exists on fertile soils, providing an exception to the rule that HNVf is present mostly in LFAs (Keenleyside et al. 2014; Lomba et al. 2014; Pointerau et al. 2007; Sutkowska et al. 2013). The chief characteristic of these areas is the structure of land ownership created by the Habsburg Empire in the

19th century and preserved in the 20th century. The area is divided into very small farms (with areas of around 1 ha) belonging to different owners. This makes it impossible to implement high-intensity, profitable agriculture. It is very important to learn the potential risks to the existence of these regions and possible directions of their development, so as to work on appropriate support strategies to make these farmlands more efficient without damaging their nature value. There are also some municipalities recognized as HNVf but not LFA located around Warsaw, Radom, and Częstochowa.

However, a large group of municipalities were categorized as non-HNVf (municipality groups 5, 6, 7, or 8 in Table 2) but LFA (42% of the non-HNVfs). They are scattered across central and western Poland (marked in blue in Figure 4). Municipalities recognized as non-HNVf but as LFAs were mostly found in municipality groups 5 or 6, hence they are dominated by low- or moderate-intensity farming systems. Non-HNVf municipalities without natural handicaps (non-LFA) are characterized by high-intensity farming systems (groups 7 or 8), and these areas should be protected to maintain biodiversity without decreasing their agricultural production.

In spite of the use of complete data on Polish farm resources, farming, and land cover features, there are still some valuable data missing—such as the proportion of extensive and semi-extensive permanent grasslands, farmer's forest, shrubs, biodiversity and distribution of various species of flora and fauna, grazed cattle, use of pesticides—for defining criteria for the reliable identification of HNVf. However, the analysis provides a well approximated identification of the extent and character of HNVf. It may contribute to methodological progress in this area, especially in the identification of HNVf areas having a limited quantity and quality of data relating to the nature value of farmland. In addition, a very important advantage of using the census data is that these data are updated every 8–10 years, which enables the monitoring of changes with respect to HNVf over time. Similar data is available in most countries; therefore, the methodology could also be adapted by them.

5. Conclusions

In this article, indicators relating to the farmland cover pattern, land cover diversity and intensity of farming systems were used in the identification of HNVf at municipality (LAU 2) level. Multivariate procedures were found to be appropriate for providing a typology of farmlands with respect to their nature value at that level. Thus, these procedures can be replicated in future periods both in Poland and in other EU member states. The map of likely occurrence and distribution of HNVf may be used as a reference point for future monitoring of the distribution of HNV farmland across the country in order to assist with planning and policy development for the rural environment. According to the best knowledge of the authors, this is the first report of such a multivariate study on the spatial distribution and characterization of HNV farmlands in Poland.

REFERENCES

Andersen, E., Baldock, D., Bennett, H., Beaufoy, G., Bignal, E., Brouwer, F., Elbersen, B., Eiden, G., Godeschalk, F., Jones, G., McCracken, D.I., Nieuwenhuizen, W., van Eupen, M., Hennekens, S., Zervas, G. (2003): Developing a High Nature Value Indicator. Report for the European Environment Agency: Copenhagen.

Beaufoy, G., Baldock, D., Clarke, J. (1994): The nature of farming – low intensity farming systems in nine European countries. IEEP, London, England

Benedetti, Y. (2017): Trends in High Nature Value farmland studies: A systematic review. European Journal of Ecology 3: 19-32. DOI: https://dx.doi.org/10.1515/eje-2017-0012

Brunbjerg, A.K., Bladt, J., Brink, M., Fredshavn, J., Mikkelsen, P., Moeslund, J.E., Nygaard, B., Skov, F., Ejrnæs, R. (2016): Development and implementation of a high nature value (HNV) farming indicator for Denmark. Ecological Indicators 59: 41-61. DOI: https://dx.doi.org/10.1016/j.ecolind.2015.09.027

Castel, J.M., Mądry, W., Gozdowski, D., Roszkowska-Mądra, B., Dąbrowski, M., Lupa, W., Mena, Y. (2010): Family dairy farms in the Podlasie province, Poland: farm typology according to farming system. Spanish Journal of Agricultural Research 8:946-961. DOI: https://dx.doi.org/10.5424/sjar/2010084-1390

EEA (2004): High Nature Value farmland – characteristics, trends and policy challenges. EEA, European Environment Agency, Copenhagen, pp. 32.

Keenleyside, C., Beaufoy, G., Tucker, G., Jones, G. (2014): High Nature Value farming throughout EU-27 and its financial support under the CAP. Report Prepared for DG

Environment. Contract No ENV B.1/ETU/2012/0035. Institute for European Environmental Policy: London.

Kikas, T., Bunce, R.G.H., Kull, A., Sepp, K. (2018): New high nature value map of Estonian agricultural land: Application of an expert system to integrate biodiversity, landscape and land use management indicators. Ecological Indicators, 94: 87-98. DOI: https://dx.doi.org/10.1016/j.ecolind.2017.02.008

Lomba, A., Alves, P., Jongman, R.H.G., McCracken, D.I. (2015): Reconciling nature conservation and traditional farming practices: a spatially explicit framework to assess the extent of High Nature Value farmlands in the European countryside. Ecology and Evolution 5: 1031-1044. DOI:10.1002/ece3.1415

Lomba, A., Guerra, C., Alonso, J., Honrado, J.P., Jongman, R., McCracken, D. (2014): Mapping and monitoring High Nature Value farmlands: Challenges in European landscapes. Journal of Environmental Management 143: 140-150. DOI: https://dx.doi.org/10.1016/j.jenvman.2014.04.029

Lomba, A., Strohbach, M., Jerrentrupd, J.S., Dauberd, J., Klimek, S., McCracken D.I. (2017): Making the best of both worlds: Can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe? Ecological Indicators 72: 118-130. DOI: https://dx.doi.org/ 10.1016/ j.ecolind.2016.08.008

Mądry, W., Mena, Y., Roszkowska-Mądra, B., Gozdowski, D., Hryniewski, R., Castel, J. (2013): An overview of farming system typology methodologies and its use in the study of pasture-based farming system: a review. Spanish Journal of Agricultural Research 11: 316-326. DOI: https://dx.doi.org/10.5424/sjar/2013112-3295

Mitchel, A. (2005): The ESRI Guide to GIS Analysis, Volume 2: Spatial Measurements and Statistics, Redlands: ESRI Press.

Musiał, W. (2007): Dezagraryzacja polskiej wsi – problemy ekonomiczne, ekologiczne i społeczne (Restricting the agricultural function of Polish rural areas – economic, ecological and social problems). Village and Agriculture136: 29-44.

Oppermann, R., Beaufoy, G., Jones, G., editors (2012): High Nature Value Farming in Europe. 35 European countries – experiences and perspectives. Verlag Regionalkultur, Ubstadt-Weiher, Germany.

Paracchini, M.L., Petersen, J.E., Hoogeveen, Y., Bamps, C., Burfield, I., Van Swaay, C. (2008): High Nature Value Farmland in Europe – an Estimate of the Distribution Patterns on the Basis of Land Cover and Biodiversity Data. JRC Scientific and Technical Reports. Joint Research Centre. Institute for Environment and Sustainability, Luxembourg.

Pointerau, P., Paracchini, M.L., Terres, J.-M., Jiguet, F., Bas, Y., Biała, K. (2007): Identification of High Nature Value Farmland in France through Statistical Information and Farm Practices Surveys. In: EUR – Scientific and Technical Research Series. Office for Official Publications of the European Communities, Luxembourg, p. 65.

Peppiette, Z., Oppermann, R., Benzler, A., Beaufoy, G., McCracken, D. (2012): Approaches to monitoring HNV farming – EU framework and country examples. In: Oppermann R., Beaufoy G., Jones G., editors, High Nature Value Farming in Europe – Verlag Regionalkultur, Ubstadt-Weiher, Heidelberg, Basel: 502-516.

Pecher, C., Tasser, E., Walde, J., Tappeiner, U. (2013): Typology of Alpine region using spatial-pattern indicators. Ecological Indicators 24: 37-47. DOI: https://dx.doi.org/10.1016/j.ecolind.2012.05.025

Ribeiro, P.F., Santos, J.L., Bugalho, M.N., Santana, J., Reino, L., Beja, P., Moreira, F. (2014): Modelling farming system dynamics in High Nature Value Farmland under policy change. Agriculture Ecosystems & Environment 183 138-144. DOI: https://dx.doi.org/10.1016/j.agee.2013.11.002

SAS (2012): SAS/STAT Software, Version 10 of the SAS System for Windows – SAS Institute Inc, Cary, NC.

Shannon, C.E. (1948): A mathematical theory of communication. The Bell System Technical Journal 27: 379–423 and 623–656.

Strohbach, M.W., Kohler, M.L., Dauber, J., Klimek, S. (2015): High Nature Value farming: From indication to conservation. Ecological Indicators 57: 557-563. DOI: https://dx.doi.org/10.1016/j.ecolind.2015.05.021

Sutkowska, B., Rozbicki, J., Gozdowski, D. (2013): Farming systems in high nature value (HNV) farmland: a case study of Wigry National Park, Poland. Polish Journal of Environmental Studies 22: 521–533.

Teillard, F., Allaire, G., Cahuzac, E., Léger, F., Malign, E., Tichit, M. (2012): A novel method for mapping agricultural intensity reveals its spatial aggregation: Implications for conservation policies – Agriculture Ecosystems & Environment 149: 135-143. DOI: https://dx.doi.org/10.1016/j.agee.2011.12.018

Van Doorn, A.M., Elbersen, B.S. (2012): Implementation of High Nature Value farmland in agri-environmental policies: What can be learned from other EU Member States? Alterra, Wageningen, p. 64. Alterra Report.

Wilk, M.B., Gnanadesikan, R. (1968): Probability plotting methods for the analysis of data. Biometrika 55 (1), 1-17, Oxford University Press on behalf of Biometrika Trust