DOI: 10.5586/asbp.3615

Publication history
Received: 2018-07-18
Accepted: 2019-02-27
Published: 2019-04-03

Handling editor
Zygmunt Kącki, Faculty of Biological Sciences, University of Wrocław, Poland

Authors' contributions
THS: research design, GIS analysis, statistical analysis, writing the manuscript; MS: research design, writing the manuscript

Funding
The study was supported by founds from the University of Wrocław and Wrocław University of Environmental and Life Sciences.

Competing interests
No competing interests have been declared.

Citation
Szymura TH, Szymura M. Spatial structure of grassland patches in Poland: implications for nature conservation. Acta Soc Bot Pol. 2019;88(1):3615. https://doi.org/10.5586/asbp.3615

ORIGINAL RESEARCH PAPER

Spatial structure of grassland patches in Poland: implications for nature conservation

Tomasz Henryk Szymura[1]*, Magdalena Szymura[2]

[1] Department of Ecology, Biogeochemistry and Environmental Protection, University of Wrocław, Kanonia 6/8, 50-328 Wrocław, Poland
[2] Institute of Agroecology and Plant Production, Faculty of Life Sciences and Technology, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24A, 50-363 Wrocław, Poland

* Corresponding author. Email: tomasz.szymura@uwr.edu.pl

Abstract

Grasslands provide wide range of ecosystem services, however, their area and quality are still diminishing in Europe. Nowadays, they often create isolated patches inside "sea" of other habitats. We have examined basic structural landscape metrics of grasslands in Poland using CORINE land use database. Characteristics for both all individual patches as well as average values for 10 × 10-km grid covering Poland were examined. We also assessed the percentage of grasslands within protected areas and ecological corridors. We found that in Poland rather small patches (0.3–1 km^2) dominate, usually located 200–500 m away from each other. The grasslands had clumped distribution, thus in Poland exist large areas where grasslands patches are separated kilometers from each other. Almost all indices calculated for 10 × 10-km^2 were correlated, i.e., in regions with high percentage of grasslands, the patches were large, more numerous, placed close to each other, and had more irregular shapes. Our results revealed that the percentage of grasslands within protected areas and ecological corridors did not differ from the average value for Poland. On the other hand, forests were significantly over-represented in protected areas and ecological corridors. These findings suggest that there is no planned scheme for grassland protection at the landscape scale in Poland. Development the scheme is urgent and needs high-quality data regarding distribution of seminatural grasslands patches. In practice, nature conservationists and managers should consider spatial processes in their plans in order to maintain grassland biodiversity.

Keywords

dispersal limitation; ecological corridors; grassland restoration; grassland management; habitat fragmentation

Introduction

Grasslands provide a wide range of ecosystem services, ranging from forage production and carbon sequestration through recreation and tourism, up to maintain high level of biodiversity [1–3]. Grasslands represent 28% of natural and seminatural habitats with high value for nature conservation in European Union (EU). It places the grasslands on the second position, after forests which consist of 50%, as ecosystems with the highest value for nature conservation in EU [4]. The grasslands in Central Europe are heterogeneous regarding to their origin, type of agricultural usage, and environmental conditions in which they develop. Therefore, they differ from monospecific, highly productive crops to species-rich seminatural meadows and pastures. A vast majority of grasslands are of anthropogenic origin, intentionally managed as pastures or for hay production. As in the case of other habitats associated with agriculture as heathlands and peatlands, their conservation status is low [5].

Because of range of ecosystem services provided by grasslands, they are a focus of interests of scientist, nature conservationists, and environment managers. To ensure provided services, different policies regarding grasslands have been applied. It includes a code of good agricultural practice [6], direct payment scheme, as well as habitat protection in the Natura 2000 program. Besides these efforts, the grasslands have been still endangered in Europe. Particularly mesic and wet seminatural grasslands are influenced by agricultural improvement for more highly productive forms involving use of chemical fertilizers instead of traditional dung. Such eutrophication is additionally increased by nitrogen pollution. It is also observed a shift of grasslands into intensive crop cultivation, especially in lowlands [7]. Another threat, particularly in Central Europe and mountainous regions, is abandoning mesic, dry, and subalpine grasslands. Mostly, this is due to the withdrawal of stock management. Such changes are often part of wider demographic, socioeconomic, and cultural shifts across large parts of the European rural landscape. In the case of wet grasslands, dependent on a high ground water table or seasonal flooding, modification of hydrographic regime usually lowers the water table level or prevent the inundation [7]. In result, the area of grasslands in Poland, as well as entire Europe, decreases. In period 1993–2011, the area of permanent grasslands in new EU member countries decreased by 11.8% [5].

The grasslands are also influenced by global changes including habitat fragmentation and entire landscape structure transformation. There are numerous studies which show that decrease of grassland patches size and connectivity reduce number of specialist species of plants [8–10] and animals [11]. Unfortunately, many grassland species show a low potential for long-distance dispersal, not exceed few meters [12–15]. Dispersal by insects (e.g., ants) and mice is also restricted to several meters [16]. A long-range dispersal can be related to dispersal by large mammals as cows and sheep [16,17]. However, in recent, highly fragmented landscape, and with lack of historical dispersal vectors such as flooding, wandering livestock, and haymaking, the effective, spontaneous recolonization of grasslands is very limited [14,18,19]. Results of observations suggest that more limiting to native grassland diversity is seed dispersal rather than competition and seed predation [20]. Therefore, many grasslands are now isolated islands within a "sea" of intensively farmed land [18]. The problem of limited dispersal seems to be even more harmful in the face of ongoing climate changes. It is assumed that rate of extinction of species with low dispersal ability will exceed 50%, while species with high dispersal ability up to 27% in minimum- and medium-level climate changes scenarios [21]. Another example of a deteriorating process, indirectly related to area and shape of habitat fragment, is the edge effect and influence from the surrounding landscape matrix enhance invasion of habitat fragments by alien species or habitat generalists [22]. Therefore, the long-term sustainability of ecosystems and the services that they generate depend on the conservation of biodiversity on a landscape scale [23–25]. The potential to maintain grasslands biodiversity in Europe is undermined, among others, by incomplete mapping and lack of consideration of habitat continuity and connectivity of existing seminatural grasslands parcels [5]. A proper management needs monitoring of habitat extends and state, and the only practical solution at large spatial extent is remote sensing [26]. In Poland, data regarding agriculturally used grasslands are provided by Central Statistical Office, but this data presents area of agriculturally used meadows and pastures within administrative units, but not location, shape, and size of particular grassland patches. The use of remote sensing in mapping of grasslands started in the early 1990s [27] in Poland, but such data have never been analyzed in quantitative manner within framework of landscape ecology.

We aimed the study at quantitative analysis of fundamental for landscape ecology traits of grassland patches in Poland. We assessed the distribution of grassland patches: size, shape, distribution, and connectivity. We also show the spatial differentiation of these landscape metrics and grasslands area, using a 10 × 10-km Atlas of Poland (ATPOL) grid system [28]. For nature conservation purposes, we assessed the efficiency of existing system of ecological corridors and nature conservation areas regarding grasslands and compared it with forests. Because such kind of examination has not been done yet in Poland, we consider our research as explorative, hypothesis-driven, and we did not raise particular hypothesis for testing. We also hope that results provided here, including maps, will be helpful for nature conservationists and managers in establishing protection needs and priorities.

Material and methods

Grasslands distribution

The CORINE land cover program provides map of land use in 44 categories, at spatial extent of entire EU. The data comes from remote sensing and ground surveys [29]. Due to technical reasons, area of the smallest mapping unit is 25 ha (e.g., square sized 500 × 500 m) and corresponds in accuracy to maps in 1:100,000 scale. Grasslands are generally considered as: "pastures" and "natural grasslands". More detailed description of these classes is shown in Tab. 1. Besides these two above-mentioned categories, the grassland patches smaller than 25 ha can be included to two other categories: "complex cultivation", and "land principally occupied by agriculture, with significant areas of natural vegetation" [29]. These two categories cannot be used for quantitative spatial analysis.

Tab. 1 CORINE classes description with corresponding EUNIS habitats and examples of phytosociological units.

CORINE level III code and name [58]		Description [59]	EUNIS habitat subgroups [60,61]	Examples of phytosociological units
2.3.1.	Pastures	Hay meadows and pastures – areas covered by permanent vegetation of numerous grass and herb species, which create a sward. Usually browsed or mowed. Also abandoned arable land used as pastures. The percentage of other agricultural land use form within 231 unit cannot exceed 25%. The cover of trees and shrubs does not exceed 20%.	Coastal dunes and sandy shores (B1)	*Koelerion albescentis* R. Tx. 1937
			Mesic grasslands (E2)	*Arrhenatherion elatioris* Koch 1926
3.2.1.	Natural grasslands	Swards and pastures of natural origin. Grass vegetation of low productivity, often placed in mountains and wetlands. The vegetation consists of, besides grasses, also herbs, mosses, lichens, and sparse shrubs. The grasslands are usually out of agricultural use. In this group, a grasslands on military training sites and on frequently flooded area are included.	Dry grasslands (E1)	*Corynephorion canescentis* Klika 1931
			Mesic grasslands (E2)	*Arrhenatherion elatioris* Koch 1926
			Seasonally wet and wet grasslands (E3)	*Calthion palustris* R. Tx. 1936 em. Oberd. 1957
			Alpine and subalpine grasslands (E4)	*Nardion* Br.-Bl. 1926 em. Oberd. 1959
			Woodland fringes and clearings and tall forb stands (E5)	*Aegopodion podagrariae* R. Tx. 1967
			Inland salt steppes (E6)	*Armerion maritimae* Br.-Bl. et De Leeuw 1936

Besides examples of phytosociological units presented here, the EUNIS habitats include also agriculturally improved and reseeded meadows and pastures. Note that phytosociological units showed here are only examples and do not present all phytosociological groups mapped in CORINE system in Poland.

Maps handling and landscape scale analysis

The original vector map of CORINE land cover provided by Chief Inspectorate of Environmental Protection [29] was cut to the administrative boundaries of Poland. It caused emerging several small patches, which area was much lower than 25 ha (original map resolution of CORINE) because the administrative boundaries divided larger grasslands patches to smaller parts. Such small patches were removed as biasing patch size distribution. This map was used to calculate grasslands acreage in entire country, to analyze patch size distribution, as well as spatial structure of grasslands, i.e., tendency to cluster or to occur with a regular or random distribution. For the last purpose, coordinates of grasslands patch centroids were used, and their spatial configuration was checked using Ripley's $K(t)$ function, which compares the observed pattern with random values. The values of $K(t)$ above the random range indicate a tendency to clustering, while below, a tendency to regular distribution in different spatial scales [30].

Next, the vector map for Poland was rasterized with resolution 30 m. This procedure again brings some artefacts by, e.g., slight increasing of path size, some simplification of patch shape, and merging some very close (<30 m) patches. However, the rasterization made possible the calculation of basic commonly used landscape metrics. This raster map was used to calculate patch shape and connectivity indices in scale of entire state, as well as metrics for the 10 × 10-km ATPOL squares [28,31]. We applied this grid system because it is well established in Poland and well adapted to recent demands of GIS techniques [28,31]. Tab. 2 lists metrics used and their brief characteristics.

Tab. 2 Landscape metrics [32] used in this study.

Metrics	Name abbreviation	Description	Comments
Class area	CA	The overall area of grasslands within studied unit.	-
Number of patches	NP	Number of grassland patches within a studied unit.	-
Area	AREA	The area of a patch.	
Shape index	SHAPE	Equals patch perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a square standard. SHAPE = 1 when the patch is square and increases without limit as patch shape becomes more irregular.	It is the simplest and perhaps most straightforward measure of shape complexity.
Euclidean nearest-neighbor distance	ENN	The distance to the nearest neighboring patch, based on shortest edge-to-edge distance.	It is perhaps the simplest measure to quantify patch isolation.
Proximity index	PROX	The sum of patch area divided by the nearest edge-to-edge distance squared between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance of the focal patch. In our research, the distance was set at 1 km. This index is dimensionless, where 0 denotes lack of grasslands patches within searched radius, while the increasing values indicate increase of grasslands areas in patch vicinity.	Index considers the size and proximity of all patches whose edges are within a specified search radius of the focal patch. It distinguishes sparse distributions of small habitat patches from configurations where the habitat forms a complex cluster of larger patches. Thus, the PROXY measures both the degree of patch isolation and the degree of fragmentation.

For each landscape index in each ATPOL square, simple arithmetic mean and area-weighted arithmetic mean were calculated. The area-weighted mean weighted the average values using patch area. Thus, the influence of largest patches is stronger than the small ones. This procedure provides a landscape-based perspective of patch structure because it reflects the average conditions of a pixel chosen at random or the conditions that an animal dropped at random into the landscape would experience [32]. Besides the above-mentioned indices, also the simple number of grassland patches per square (NP) was counted. For these calculations, only ATPOL squares which percentage of area within Polish administrative terrestrial boundaries exceed 50% were used. There were 3,084 squares in sum. The raster map was also used to create map showing distance from each raster to the nearest grassland patch.

Grasslands percentage within protected areas such as national parks and nature reserves, Nature 2000 sites, landscape parks, as well as in ecological corridors were calculated. The maps of protected areas and ecological corridors were derived from [33]. We also calculated the percentage of forests which consist of protected areas and landscape corridors for comparison. We checked whether the percentages of grasslands and forests within protected areas differ from average percentage for entire country, using chi-squared test. The results indicate overrepresentation, underrepresentation, or average proportion of grassland and forests within these protected areas.

The map handling and editing were done in SAGA [34] and QGIS software, while the landscape metrics were calculated using FRAGSTATS [32]. The spatial pattern of grasslands distribution was tested by Ripley's $K(t)$ function using spatstat [35] package in R environment. The maps were plotted against of boundaries of 16 voivodeships – the highest-level administrative subdivision of Poland, for a better understanding of the geographical space within territory of Poland

Results

The total calculated area of grasslands based on CORINE is 27,771 km^2 in 17,623 patches (Fig. 1). The most numerous were grassland patches sized 0.3–1 km^2 (median value = 0.57 km^2), while the area of largest patch found was 522 km^2 (Fig. 1, Fig. 2A). Due to the methodology, the smallest patches were sized 0.25 km^2. Gross total area of grasslands in Poland formed rather small and medium-size patches: 96% of total grassland area consists of patches sized up to 5 km^2 (Fig. 2A). The grassland patches were most often placed in distance 200–500 m from each other (Fig. 2B; median value = 323 m). Patches consisting of about 81% of grasslands number in Poland were placed no further than 1 km from each other (Fig. 2B). The largest distance found between patches was 12 km. The relatively low distance between patches resulted from strong tendency of grasslands to clustering (Fig. 2C). The shape of grasslands was usually quite complex (Fig. 2E). The basic descriptive statistics of calculated metrics are presented in Tab. S1.

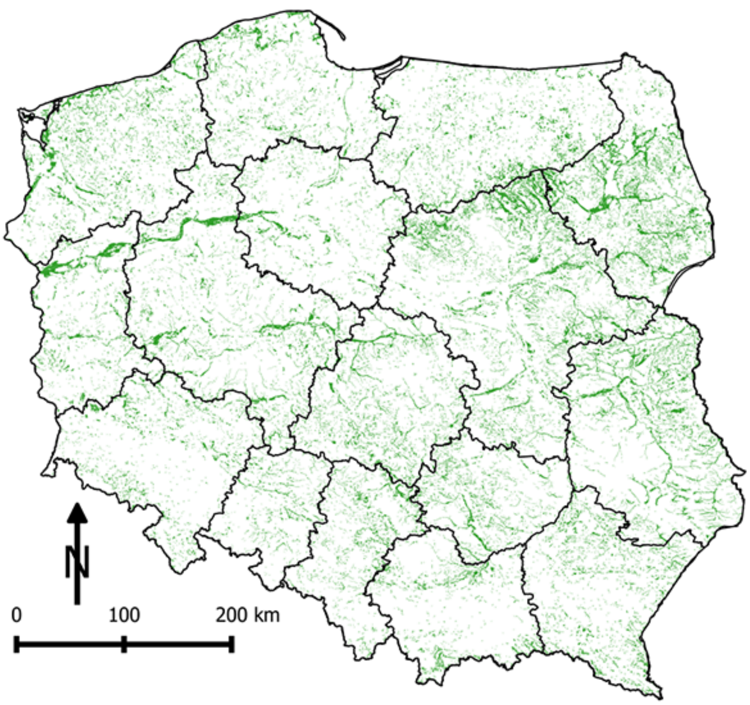

Fig. 1 Distribution of grasslands in Poland (green) on the background of basic administrative units (voivodeships).

Countrywide, differentiation in grasslands distribution was observed (Fig. 1, Tab. S2), which results in the differentiation of spatial isolation of the grassland patches (Fig. 3). Almost all the calculated landscape indices for ATPOL 10 × 10-km squares were correlated (Tab. S3).

The percentage of grasslands that form part of the ecological corridors did not differ from the random value (Tab. 3; insignificant values of tests). This was also determined

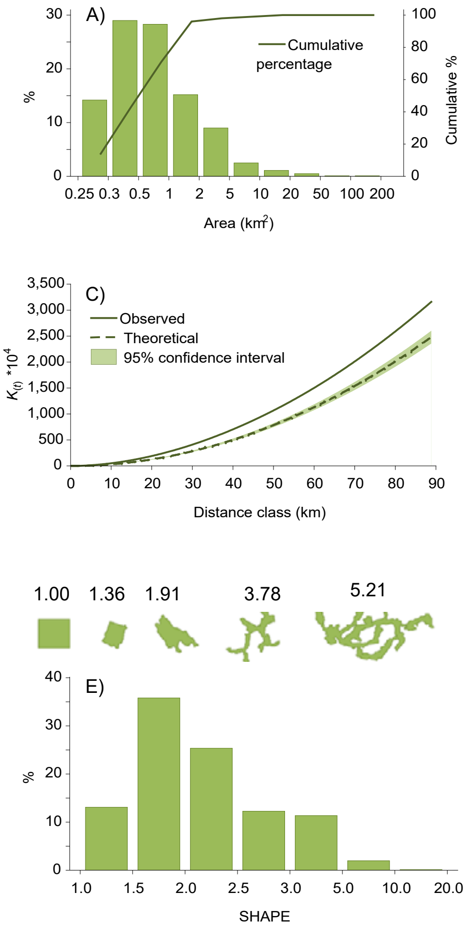

Fig. 2 Distribution of patch area (**A**), Euclidian distance to nearest patch (ENN) (**B**), proximity index (PROX) (**D**), and shape index (SHAPE) (**E**) as well as values of Ripley's $K(t)$ function (**C**) in distance classes for grasslands patches centroids (observed) and random values (theoretical). (**A,B,D**) Besides the histograms, the lines showing cumulative percentages are shown. (**E**) A square and a few examples of other grasslands patches with different SHAPE values are present.

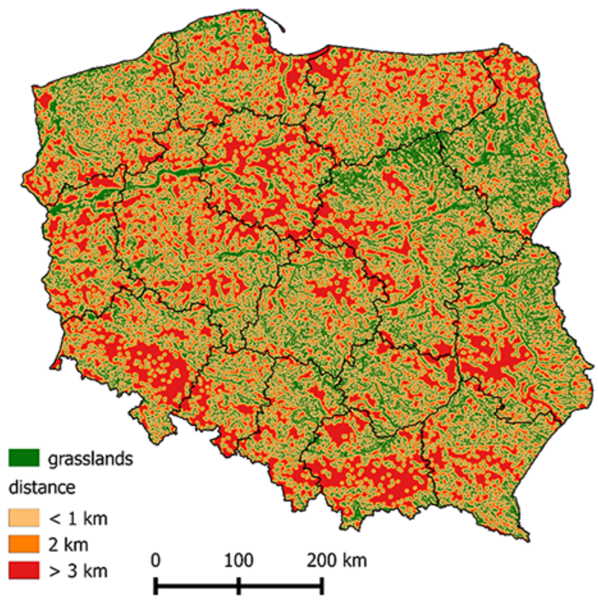

Fig. 3 Distances for nearest grassland patch in Poland on the background of basic administrative units (voivodeships). The distance class, according to [19,39,40], represents areas with possible migration between grassland patches (<1 km), hampered migration (1–2 km), and with restricted gene flow (>3 km). Note that for numerous grassland species, the possible range of dispersal is counted in a few meters only [12,15,38].

Tab. 3 Comparison of percentage of grasslands and forests in entire country (Poland) as well as in ecological corridors and protected areas, divided further into national parks with nature reserves, Natura 2000 sites, as well as landscape parks. The results of statistical tests (chi-squared test and *p*) are shown.

	Grasslands			Forests		
	Percentage	Chi-squared	*p*	Percentage	Chi-squared	*p*
Poland	8.90	-	-	31.5	-	-
Ecological corridors	9.10	0.06	0.804	58.1	13.69	0.000
Protected areas	11.53	0.48	0.489	48.9	6.75	0.009
Reserves and national parks	9.30	0.06	0.804	64.8	21.80	0.000
Natura 2000 sites	14.40	1.79	0.192	53.7	9.05	0.003
Landscape parks	7.90	0.06	0.799	47.7	6.05	0.014

in the case of protected areas, regardless of whether these were reserves and national parks, landscape parks, or Natura 2000 sites. It was in contrast with forests, which were significantly overrepresented in ecological corridors and all forms of nature protection (Tab. 3).

Discussion

The landscape characteristics

The results highlighted regional differentiation of grasslands distribution. In Poland, the lowland grasslands concentrate along watercourses, in river valleys and local depressions [36,37], and the managed meadows and grasslands are placed usually on moderate and poor soils, unsuitable as arable lands [37]. The spatially structured pattern of landrelief attributes and soil properties distribution caused also strong tendency of grassland patches to clustering (Fig. 2A). It results in three phenomena: first, domination of grassland patches placed in distance shorter than 500 m from other grasslands; secondly, because the area of grassland patches is usually small, the dominant values of PROXY index are relatively low; and thirdly, in presence in Poland large areas where grasslands are scarce. However, the EEN between patches seems to be not particularly large, the distance 200–500 m is practically impassable for numerous grassland species, in face of lack of migrating animals and hay transfer. Considering the low pace of dispersal of many grassland species [12,15,38], the possibility of reaching another patch theoretically will take centuries, in situation of lack of long-range dispersal vectors as wandering cattle, hay transfer, or/and floods (e.g., [12–15,18,19,38]). Because the dispersal ability of particular grassland species differs considerably, it is difficult to establish versatile zones of efficient colonization. In studies of [13], only about 50% of seminatural grassland species was able to colonize adjacent ex-arable field margin during 50 years, and their number decreased with distance to grassland, which ranged from 0 up to only 10 m. On the other hand, in White Carpathian Mts, with high level of grassland species richness, the surrounding area of ca. 9 km^2 was found as providing diaspores of some species for spontaneous colonization of dry grasslands [19]. But even in such high-value landscape, only 57% of target species typical to dry grasslands colonized reestablished grasslands during 31 years of the succession [19]. It can be stated that some target species should be placed in distance lower than 1–2 km from colonized habitat, while at distance above 3 km, gene flow between populations is limited, e.g., by lack of cross-pollination between populations [19,39,40]. Also, the dominance of low values of PROXY is rather a bad message from the perspective of nature conservation at a landscape scale. The studies from Europe reveal positive correlation between the PROXY values and overall plant species richness [41] as well as threatened and specialist species richness in landscape [11,42].

The shape of grassland patches in Poland is rather isodiametric (Fig. 2E), which suggests that the area of patch is relatively high comparing to length of patch edge.

The low ratio of perimeter to area should be beneficial for grassland-specialist species, limiting expansion of ubiquitous species and invasion of alien species [22]. On the other hand, in Europe, the complexity of patch shape is considered as an indicator of low intensification of agriculture and can be used as proxy for species richness [43]. In Poland, the high SHAPE values can be also considered as indicators of rather low agriculture intensity and high fraction of grasslands in landscape (Tab. S3, Fig. 1, Fig. 3), as the SHAPE is correlated with grassland acreage and patch number.

Finally, the map of distance distribution (Fig. 3) reveals large areas where grasslands patches are located kilometers from each other. In such areas, the particular patches of grasslands are usually small, as, e.g., on areas with high-productive arable lands on fertile soils in Lower Silesia. It additionally increases the probability of random extinction of isolated populations [38]. Because of the correlation between most of calculated landscape indices in 10 × 10-km grid, we assume that the map of distance distribution can serve as a good proxy of landscape scale state of grasslands value in Poland, indicating areas where grasslands protection and restoration should be a priority, and where the structural connectivity between grasslands seems to be still efficient.

Data quality

The area of permanent grasslands used for agriculture in Poland is 30,880 km^2 according to Central Statistical Office [44]. It reveals some underestimation of grasslands area calculated according to CORINE (27,771 km^2 – 89.9% of value calculated by Central Statistical Office [44]). The simplest explanation of this underestimation is lack of consideration of small grasslands patches sized below 0.25 km^2, which were included in other types of land use due to CORINE methodology; however, the reason for the underestimation might be more complex. On the one hand, this bias can be even larger since the CORINE data consider also grassland areas not used for agriculture, which are not taken into consideration by Central Statistical Office. On the other hand, the results of another study [45] suggest that the Central Statistical Office data overestimate the real agricultural areas by including also abandoned fields. Additionally, the areas of grasslands derived from CORINE show not only the high-value seminatural grasslands, but also agriculturally used meadows for hay production with little value for nature protection and limited number of ecosystem services provided. Potentially, the percentage of seminatural, high-value grasslands only within protected areas and ecological corridors can be higher than results presented there. It is hard to assess the effect of naturally fragmented grassland types, e.g., inland dune grasslands on the results of this analysis, since even their total area is unknown, which suggests that more precise data for grasslands distribution are needed. Unfortunately, there is a problem with grasslands mapping. The particular challenges are: (***i***) the small spatial extent of such habitats, (***ii***) their spectral similarity, and (***iii***) the high spatial, structural and temporal diversity of the vegetation composition [26]. It needs not only high-resolution data but also intra-annual time series for the discrimination of habitats via the distinction of different vegetation growth phases. The capacity to differentiate individual grassland habitat classes using remote sensing data is not reported [26]. Moreover, it should be emphasized that presented here indices of landscape connectivity refer to structural landscape features, but not necessarily functional connectivity. The metrics calculated based on used maps measure the physical composition or configuration of the patch mosaic, but do not focus on individual perspective of the landscape [46].

Implication for nature conservation

Taking into consideration only quantitative data related to grasslands (i.e., regardless of grasslands quality), systems of ecological corridors and protected areas could be established equally well at random in Poland (Tab. 3). Moreover, in Poland, there is no "grassland reserve" category [36]. As a result, the fraction of grasslands in protected areas systems is almost two times smaller in Poland than the average for EU [4]. It suggest that there is no national scheme for grassland protection and a well-thought-out system of ecological corridors for grasslands.

In opinion of agriculture practitioner, a reasonable way to maintain productive grasslands with high nature conservation value in Poland is organic farming [47]. Unfortunately, some specialists still consider nature-friendly grassland management (so-called "environmental direction") as much less perspective strategy than highly productive agriculture, and possible to introduce only on restricted areas [48]. In some analyses, this environmental direction is not considered at all [49]. However, the conservation of grasslands should be planned at landscape scale [13,24,40]. Taking into consideration the ongoing global change and observed loss of seminatural grassland habitats, the conservation needs active restoration of grasslands [50]. To preserve a diversity of species-rich grasslands remnants in agricultural landscape, it is necessary to re-establish the connection between isolated grasslands patches. A way to reach this is a grasslands restoration on abandoned agricultural lands. The grassland restoration on abandoned cropland is one of the most frequently applied habitat restoration actions in Europe [51]. Unfortunately, in Poland such actions are undertaken rather sporadically (see, e.g., [52,53]) and there is no agenda to collect data regarding the restoration. The simple sowing of seed mixtures is only the first phase of species-rich grasslands restoration, the second phase relies on spontaneous colonization of grassland species from surrounding landscape [19], but it again needs connection between grassland patches. Moreover, a local seed mixtures should be used for successful restoration (e.g., [54,55]), and in Poland there is no agenda to support distribution of local seed mixtures of species-rich semi-natural meadows [52,56].

In practice, in the case of Natura 2000 sites, environmental managers are faced to make a decision whether to protect particular patch of habitat or not. There is no unambiguous practical guidance in such choice, thus decisions are usually undertaken considering percentage loss of given habitat area in a particular region [52,57]. We hope that maps presented here indicating areas of exceptionally low structural connectivity between grasslands will help decision makers establish conservation priorities, at a landscape scale, for seminatural grasslands protection. If a grassland has to be established as a form of compensation of harms caused by an investment, the location of establishment site should be considered carefully. Taking into consideration the spatial structure of grasslands, the sites restored by commercial seed mixture should be located next to the already existing seminatural grasslands in order to enable species migration. The browsing by animals will be beneficial for grassland species dispersal into newly established site from adjacent seminatural grassland. In the case of restoration of grasslands on sites without high-value grasslands in neighborhood, the hay transfer should be applied to provide propagules of target species. Additionally, it should be pointed out that the distances included in Fig. 3 concern species with effective long-range dispersal only, while dispersal of many grasslands species, e.g., *Geranium pratense*, *Knautia arvensis*, *Silaum silaus*, *Serratula tinctoria*, *Tragopogon pratensis*, is limited to a few meters or less [12,15,38].

Conclusion

The grasslands distribution in Poland is not optimal considering nature conservation: the patches are usually small, what enhances the risk of local species extinction, and located from each other in distances which hamper population re-establishing from surrounding patches. There are large areas where grasslands patches are placed kilometers from each other. The existing systems of protected areas and ecological corridors are not suited for grasslands protection. There is a need for establishing of a plan of grassland protection at landscape scale which will help nature conservationists in grassland management. Such system should include protected areas and ecological corridors. Establishing of such plan requires, among others, a new, precise, and public data about seminatural grasslands patches distribution. Considering the pace at which the area of seminatural grasslands diminishes and the ongoing global changes, the need for establishing such a system is urgent.

Acknowledgments

We would like to thank MSc Marta Czarniecka-Wiera (Instiitute of Technology and Life Sciences, Falenty) and MSc Katarzyna Łapińska (Regional Directorate for Environmental Protection, Wrocław) for helpful comments which significantly improved the article.

Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/asbp/rt/suppFiles/asbp.3615/0:

Tab. S1 Basic descriptive statistics of landscape metrics for grasslands in Poland.

Tab. S2 Basic descriptive statistics of landscape metrics for ATPOL 10 × 10-km squares.

Tab. S3 Pearson ranks correlations between landscape metrics for grasslands in ATPOL squares.

Fig. S1 Landscape metrics for ATPOL 10 × 10 squares on the background of basic administrative units and 100 × 100-km ATPOL squares.

References

1. Lemaire G, Hodgson J, Chabbi A, editors. Grassland productivity and ecosystem services. Wallingford: CABI; 2011. https://doi.org/10.1079/9781845938093.0000
2. Hönigová I, Vačkář D, Lorencová E, Melichar J, Götzl M, Sonderegger G, et al. Survey on grassland ecosystem services. Report to the EEA – European Topic Centre on Biological Diversity. Prague: Nature Conservation Agency of the Czech Republic; 2012.
3. Habel JC, Dengler J, Janišová M, Török P, Wellstein C, Wiezik M. European grassland ecosystems: threatened hotspots of biodiversity. Biodivers Conserv. 2013;22(10):2131–2138. https://doi.org/10.1007/s10531-013-0537-x
4. Mücher CA, Hennekens SM, Bunce RG, Schaminée JH, Schaepman ME. Modelling the spatial distribution of Natura 2000 habitats across Europe. Landscape Urban Plan. 2009;92(2):148–159. https://doi.org/10.1016/j.landurbplan.2009.04.003
5. Pe'er G, Dicks LV, Visconti P, Arlettaz R, Báldi A, Benton TG. EU agricultural reform fails on biodiversity. Science. 2014;344(6188):1090–1092. https://doi.org/10.1126/science.1253425
6. Duer I, Fotyma M, Madej A. Kodeks dobrej praktyki rolniczej. Warszawa: Fundacja Programów Pomocy dla Rolnictwa; 2004.
7. Janssen JA, Rodwell JS, Criado MG. European red list of habitats. Part 2. Terrestrial and freshwater habitats. Luxembourg: Publications Office of the European Union; 2016.
8. Soons MB, Messelink JH, Jongejans E, Heil GW. Habitat fragmentation reduces grassland connectivity for both short-distance and long-distance wind-dispersed forbs. J Ecol. 2005;93(6):1214–1225. https://doi.org/10.1111/j.1365-2745.2005.01064.x
9. Helm A, Hanski I, Pärtel M. Slow response of plant species richness to habitat loss and fragmentation. Ecol Lett. 2006;9(1):72–77. https://doi.org/10.1111/j.1461-0248.2005.00841.x
10. Cousins SA. Extinction debt in fragmented grasslands: paid or not? J Veg Sci. 2009;20(1):3–7. https://doi.org/10.1111/j.1654-1103.2009.05647.x
11. Brückmann SV, Krauss J, Steffan-Dewenter I. Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. J Appl Ecol. 2010;47(4):799–809. https://doi.org/10.1111/j.1365-2664.2010.01828.x
12. Bischoff A. Dispersal and establishment of floodplain grassland species as limiting factors in restoration. Biol Conserv. 2002;104(1):25–33. https://doi.org/10.1016/S0006-3207(01)00151-3
13. Öster M, Ask K, Römermann C, Tackenberg O, Eriksson O. Plant colonization of ex-arable fields from adjacent species-rich grasslands: the importance of dispersal vs. recruitment ability. Agric Ecosyst Environ. 2009;130(3–4):93–99. https://doi.org/10.1016/j.agee.2008.12.005
14. Kiehl K, Kirmer A, Donath TW, Rasran L Hölzel N. Species introduction in restoration projects – evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. Basic Appl Ecol. 2010;11(4):285–299. https://doi.org/10.1016/j.baae.2009.12.004
15. Baasch A, Engst K, Schmiede R, May K, Tischew S. Enhancing success in grassland restoration by adding regionally propagated target species. Ecol Eng. 2016;94:583–591. https://doi.org/10.1016/j.ecoleng.2016.06.062

16. Bakker JP, Poschlod P, Strykstra RJ, Bekker RM, Thompson K. Seed banks and seed dispersal: important topics in restoration ecology. Acta Botanica Neerlandica. 1996;45(4):461–490. https://doi.org/10.1111/j.1438-8677.1996.tb00806.x

17. Kuiters AT, Huiskes HPJ. Potential of endozoochorous seed dispersal by sheep in calcareous grasslands: correlations with seed traits. Appl Veg Sci. 2010;13(2):163–172. https://doi.org/10.1111/j.1654-109X.2009.01058.x

18. Walker KJ, Stevens PA, Stevens DP, Mountford JO, Manchester SJ, Pywell RF. The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. Biol Conserv. 2004;119(1):1–18. https://doi.org/10.1016/j.biocon.2003.10.020

19. Prach K, Fajmon K, Jongepierová I, Řehounková K. Landscape context in colonization of restored dry grasslands by target species. Appl Veg Sci. 2015;18(2):181–189. https://doi.org/10.1111/avsc.12140

20. Pinto SM, Pearson DE, Maron JL. Seed dispersal is more limiting to native grassland diversity than competition or seed predation. J Ecol. 2014;102(5):1258–1265. https://doi.org/10.1111/1365-2745.12282

21. Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, et al. Extinction risk from climate change. Nature. 2004;427(6970):145. https://doi.org/10.1038/nature02121

22. Kiviniemi K, Eriksson O. Size-related deterioration of semi-natural grassland fragments in Sweden. Divers Distrib. 2002;8(1):21–29. https://doi.org/10.1046/j.1366-9516.2001.00125.x

23. Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecol Lett. 2005;8(8):857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

24. Aavik T, Helm A, Restoration of plant species and genetic diversity depends on landscape-scale dispersal. Restor Ecol. 2017;26(2):92–102. https://doi.org/10.1111/rec.12634

25. Durka W, Michalski SG, Berendzen KW, Bossdorf O, Bucharova A, Hermann JM, et al. Genetic differentiation within multiple common grassland plants supports seed transfer zones for ecological restoration. J Appl Ecol. 2017;54(1):116–126. https://doi.org/10.1111/1365-2664.12636

26. Schuster C, Schmidt T, Conrad C, Kleinschmit B, Förster M. Grassland habitat mapping by intra-annual time series analysis – comparison of RapidEye and TerraSAR-X satellite data. Int J Appl Earth Obs Geoinf. 2015;34:25–34. https://doi.org/10.1016/j.jag.2014.06.004

27. Ciołkosz A, Dąbrowska-Zielińska K. Wykorzystanie teledetekcji satelitarnej do szacowania produkcji trwałych użytków zielonych. Prace Instytutu Geodezji i Kartografii. 1993;40(1):85–102.

28. Zając A. Atlas of distribution of vascular plants in Poland (ATPOL). Taxon. 1978;27(5–6):481–484. https://doi.org/10.2307/1219899

29. Główny Inspektorat Ochrony Środowiska. CORINE Land Cover – CLC 2012 [Internet]. 2012 [cited 2018 May 6]. Available from: http://clc.gios.gov.pl/index.php/clc-2012/o-clc2012

30. Ripley BD. Spatial statistics. New York, NY: Wiley and Sons; 1981. https://doi.org/10.1002/0471725218

31. Verey M. Teoretyczna analiza i praktyczne konsekwencje przyjęcia modelowej siatki ATPOL jako odwzorowania stożkowego definiującego konwersję współrzędnych płaskich na elipsoidę WGS 84. Fragm Florist Geobot Pol. 2017;24(2):469–488.

32. McGarigal K, Cushman SA, Ene E. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst [Internet]. 2012 [cited 2018 May 6]. Available from: http://www.umass.edu/landeco/research/fragstats/fragstats.html

33. Generalna Dyrekcja Ochrony Środowiska. Dostęp do danych geoprzestrzennych [Internet]. 2018 [cited 2018 May 6]. Available from: http://www.gdos.gov.pl/dane-i-metadane

34. Conrad O, Bechtel B, Bock M, Dietrich H, Fischer E, Gerlitz L, et al. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. Geosci Model Dev. 2015;8:1991–2007. https://doi.org/10.5194/gmd-8-1991-2015

35. Baddeley A, Turner R, Rubak E. Package "spatstat". The comprehensive R archive network [Internet]. 2014 [cited 2018 May 6]. Available from: https://cran.r-project.org/package=spatstat

36. World Conservation Monitoring Centre. The lowland grasslands of Central and Eastern Europe. Cambridge: IUCN Publications Unit; 1991. (Environmental Research Series, International Union for Conservation of Nature and Natural Resources; vol 4).

37. Jankowska-Huflejt H, Domański JP. Aktualne i możliwe kierunki wykorzystania trwałych użytków zielonych w Polsce. Woda – Środowisko – Obszary Wiejskie. 2008;8:31–49.

38. Diacon-Bolli JC, Edwards PJ, Bugmann H, Scheidegger C. Wagner HH. Quantification of plant dispersal ability within and beyond a calcareous grassland. J Veg Sci. 2013;24(6):1010–1019. https://doi.org/10.1111/jvs.12024

39. Aavik T, Holderegger R, Edwards PJ, Billeter R. Patterns of contemporary gene flow suggest low functional connectivity of grasslands in a fragmented agricultural landscape. J Appl Ecol. 2013;50(2):395–403. https://doi.org/10.1111/1365-2664.12053

40. Helm A. Habitat restoration requires landscape-scale planning. Appl Veg Sci. 2015;18(2):177–178. https://doi.org/10.1111/avsc.12159

41. Deutschewitz K, Lausch A, Kühn I, Klotz S. Native and alien plant species richness in relation to spatial heterogeneity on a regional scale in Germany. Global Ecology and Biogeography. 2003;12(4):299–311. https://doi.org/10.1046/j.1466-822X.2003.00025.x

42. Honnay O, Piessens K, van Landuyt W, Hermy M, Gulinck H. Satellite based land use and landscape complexity indices as predictors for regional plant species diversity. Landsc Urban Plan. 2003;63(4):241–250. https://doi.org/10.1016/S0169-2046(02)00194-9

43. Moser D, Zechmeister HG, Plutzar C, Sauberer N, Wrbka T, Grabherr G. Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. Landsc Ecol. 2002;17(7):657–669. https://doi.org/10.1023/A:1021513729205

44. Central Statistical Office [Internet]. 2017 [cited 2018 May 5]. Available from: http://stat.gov.pl/en/

45. Szymura M, Szymura TH, Wolski K. Invasive *Solidago* species: how large area do they occupy and what would be the cost of their removal? Pol J Ecol. 2016;64(1):25–34. https://doi.org/10.3161/15052249PJE2016.64.1.003

46. Tischendorf L, Fahrig L. On the usage and measurement of landscape connectivity. Oikos. 2000;90(1):7–19. https://doi.org/10.1034/j.1600-0706.2000.900102.x

47. Jankowska-Huflejt H. The need of protecting permanent grasslands as a premise for the development of organic meadow farms. Journal of Research and Applications in Agricultural Engineering. 2016;61(3):186–192.

48. Wasilewski Z. Stan obecny i kierunki gospodarowania na użytkach zielonych zgodne z wymogami Wspólnej Polityki Rolnej. Woda – Środowisko – Obszary Wiejskie. 2009;9:169–184.

49. Jankowski K, Kolczarek R, Jankowska J, Sosnowski J. The strategies of grassland management in farms of northeastern part of Poland. Journal of Life Sciences. 2013;7(7):727–731.

50. Török P, Helm A. Ecological theory provides strong support for habitat restoration. Biol Conserv. 2017;206:85–91. https://doi.org/10.1016/j.biocon.2016.12.024

51. Török P, Vida E, Deák B, Lengyel S, Tóthmérész B. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. Biodiv Conserv. 2011;20(11):2311–2332. https://doi.org/10.1007/s10531-011-9992-4

52. Kącki Z, Szymura M. Szkody w siedliskach łąkowych. In: Lubaczewska S, editor. Strażnicy Natury 2000: zapobieganie szkodom w praktyce. Wrocław: Fundacja EkoRozwoju; 2010. p. 67–90.

53. Pawluśkiewicz B, Janicka M, Piekut K. Restoration of *Cnidion dubii* meadows on Warsaw cross-section of the Middle Vistula Valley. Annals of Warsaw University of Life Sciences – SGGW. Land Reclamation. 2017;49(4):277–287. https://doi.org/10.1515/sggw-2017-0022

54. Kiehl K, Kirmer A, Shaw N, Tischew S Guidelines for native seed production and grassland restoration. Newcastle upon Tyne: Cambridge Scholar Publishing; 2014.

55. Bucharova A, Bossdorf O, Hölzel N, Kollmann J, Prasse R, Durka W. Mix and match: regional admixture provenancing strikes a balance among different seed-sourcing strategies for ecological restoration. Conserv Genet; 2018;20:7–17. https://doi.org/10.1007/s10592-018-1067-6

56. Swacha G, Botta-Dukát Z, Kącki Z, Pruchniewicz D, Żołnierz L. A performance comparison of sampling methods in the assessment of species composition patterns and environment–vegetation relationships in species-rich grasslands. Acta Soc Bot Pol. 2017;86(4):3561. https://doi.org/10.5586/asbp.3561
57. Pawlaczyk P. Kryteria szkody w środowisku. In: Lubaczewska S, editor. Strażnicy Natury 2000: zapobieganie szkodom w praktyce. Wrocław: Fundacja EkoRozwoju; 2010. p. 47–65.
58. European Environmental Agency. Corine land cover [Internet]. 2018 [cited 2018 May 6]. Available from: https://www.eea.europa.eu/publications/COR0-landcover
59. Główny Inspektorat Ochrony Środowiska. CORINE Land Cover – CLC. Definicje klas [Internet]. 2018 [cited 2018 May 6]. Available from: http://clc.gios.gov.pl/index.php/o-clc/definicje-klas
60. European Environment Agency. Crosswalk between EUNIS habitats classification and Corine land cover [Internet]. 2014 [cited 2018 May 6]. Available from: https://www.eea.europa.eu/ds_resolveuid/bcc6db38c6a24c739c655e897ed730c5
61. Schaminée JH, Chytrý M, Dengler J, Hennekens SM, Janssen JA, Jiménez-Alfaro B, et al. Development of distribution maps of grassland habitats of EUNIS habitat classification [Internet]. 2016 [cited 2018 May 6]. Available from: https://forum.eionet.europa.eu/nrc-biodiversity/library/eunis_classification/report-2016-eunis-grasslands-ii-incl-plot-maps/download/en/1/Report%202016%20EUNIS%20Grasslands%20II%20incl%20plot%20maps.pdf?action=view

