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A methodology for verifying/determining the boundaries of Game Management Regions: A case study of the Regional Directorate of the State Forests in Lublin (Poland)

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Abstract

Wildlife management is an integral part of forest management, and game animals should be considered an essential part of the forest ecosystem and agroecosystems in which the flow of energy changed fundamentally during the 20th century due to the use of fertilisers, pesticides, and modern technologies. An approximately four-fold increase in the production of crops brought with it an increase in the number of ungulates in the world. The tasks of foresters and hunters in wildlife management include creating the best suitable living conditions for animals and mitigating conflicts between forest animals and human activities. This necessitates the creation and implementation of modern land units called Game Management Regions (GMRs) in Poland. This concept was defined in the Polish Hunting Law primarily for managing big game populations. The aim of the GMRs is to ensure year-long management of game populations within their respective ranges. Long-term Hunting Management Plans were developed for each GMR, serving as the basis for adopting management directions, and achieving the desired state of the game population as recorded in the multi-year plan (typically spanning ten years).

However, experiences and the current situation reveal several weaknesses in the functioning of these divisions, including rapid changes in the environment, particularly the emergence of barriers like highways and new buildings. This research aimed to develop a method for determining or verifying the boundaries of the GMRs based on objective criteria as a case study hosted by the Regional Directorate of State Forests in Lublin. During the conducted analysis we examined data provided by the Regional Directorate of State Forests (RDSF) in Lublin, including information on the current density of red deer (*Cervus elaphus*), forest cover, forest patch fragmentation, categories of hunting districts, ecological corridors, as well as existing, under-construction and planned highways and expressways.

The boundaries of the GMRs were determined by aggregating hunting districts with similar characteristics using GIS software while considering ecological barriers. The analysis results indicated the need to establish 12 divisions instead of 8, with significant deviations from the previous delimitation. The obtained results underscore the necessity of verifying the boundaries of the GMRs nationwide.

Keywords: large-scale game management; big game; Game Management Region; hunting plans

Introduction

Contemporary hunting has developed two organisational systems, namely the district and the licensing systems (Putman et al. 2010). The District System consists of leasing hunting districts by hunting clubs at the request of the Polish Hunting Association after seeking the opinion of the commune head (mayor or president of the city) and the relevant agricultural chamber, for not less than ten years. According to Polish Law on Hunting (Sejm 1995), a hunting district (hunting area) constitutes an area of continuous land with boundaries, at most three thousand hectares, where conditions for hunting activities exist. Hunting districts are categorised into forested districts (where forested lands constitute at least 40% of the total area) and open districts (where forested lands comprise less than 40% of the total area). These areas are established based on the following principles: 1) optimising the fulfilment of needs for conservation and developing game species; 2) avoiding the division of water bodies; and 3) determining boundaries based on natural or distinct landmarks on the terrain. Hunting districts are additionally categorised based on game population indicators, factors influencing their habitat, and the hunting values of the district, which are expressed as very good, good, average, poor or very poor (Ministerstwo Środowiska 2019). However, after many years of conducting game management based on hunting districts, the quality of the cervids (mainly large deer, such as moose or red deer) has declined, and imperfect inventory methods have led to disruptions in the populations of various age and sex groups of game species (Bobek et al. 1984, 1994). Proper management of moose or red deer populations within the existing spatial model became challenging and often even impossible. Therefore, in 1997, the so-called Game Management Regions (GMRs) were established based on economic, but above all, ecological principles, under the assumption that rational management can only be achieved for entire populations rather than their artificially divided parts (Dzięciołowski 1979, 2011, Bereszta and Przybylska 2011). Furthermore, rational population management is only possible when the same rules, methods and management approaches are binding for all wildlife managers and hunting ground users. As a result, new territorial units for hunting management were established, covering the entire areas of specific big game populations, aimed at addressing or mitigating issues resulting from the overpopulation of certain game species (e.g. causing damage, transmitting pathogens) and attempts have been made to develop a uniform method of managing populations in entire physiographic units (e.g. large forest areas, mountain ranges, river valleys etc.). These units also enabled the implementation of practical measures to support game populations, such as reintroduction, feeding, predator control, food production, etc. (Dzięciołowski 1979, 2011, Bereszta and Przybylska 2011).

Several changes have occurred in the past 25 years, including the expansion of urban agglomerations and connections between road networks and transportation hubs. Road and urban infrastructure consume and fragment large areas once wildlife habitats. Between 2002 and 2022, 1,340 km of new highways, 2,760 km of expressways and 100 bypasses with a total length of 1,414.2 km (Generalna Dyrekcja Dróg Krajowych i Autostrad 2023) were constructed in Poland. In 2021 alone, Poland added 246.4 km of expressways and 48.3 km of highways. As of the end of 2021, the public road network in Poland extended to 429,800 km, with hard-surfaced roads covering 315,500 thousand km (comprising 73.4% of the total length of public roads). In the Lublin Voivodeship, the area of hard surface roads increased from 21,325.1 km (2011) to 23,936.2 km (2022), which was in 2011 84.9 km/100 km^2 and in 2022 already 95.3 km/100 km^2. Expressways were also built, which accounted for only 4.2 km in 2011 and as much as 232.1 km in 2022 (Główny Urząd Statystyczny 2011, 2022).

Over ten years, Poland constructed 1.7 million new apartments, accounting for 11.3% of the total housing stock, while urbanisation reached 60%. In the Lublin Voivodeship, urbanisation reached 48%, the housing stock increased by 330% and the increase rate of the number of apartments in cities was higher compared to the average for Polish cities (Rodzoś and Wesołowska 2012, Główny Urząd Statystyczny 2023).

In addition to physically occupying animals' living space, all these factors negatively impact their existence. This pertains to the fragmentation of the remaining wildlife-friendly landscapes by barriers that disrupt or prevent their movement. This severe threat can be mitigated by using ecological corridors that connect individual "islands" of habitats or by organising costly resettlements to bolster declining populations. However, acting at the planning stage is crucial, such as creating optimal Long-term Hunting Management Plans that provide a consistent trend for the next ten years in areas with similar conditions for entire populations of large herbivores. This approach aligns with the intention of the IUCN Policy Statement on the Sustainable Use of Wild Living Resources adopted at the World Congress of the World Conservation Union in 2000 (2000).

Ecological arguments favour managing animal populations on areas larger than 3,000 hectares, including the analysed size of the home range occupied by red deer or moose. The size of the home range of *Cervus elaphus* in Europe is very different and is given by a whole series of factors (Wood 2000) (Table 1). It is worth noting that the individual ranges of red deer in Białowieża National Park were significantly larger than those observed in Europe, suggesting that in primaeval forests with large predators (a historical situation for most of Europe), red deer require extensive forest complexes to meet seasonal and annual needs (Jędrzejewska et al. 1994, Padaiga 1996, Kamler et al. 2008). Research has shown that red deer can exhibit territorial expressive behaviour, especially during the rutting season (Carranza et al. 1990, Belova 2001), and return to the same rutting sites each year (Clutton-Brock et al. 1982a, b, Belova 2001). Therefore, in our opinion, this is a crucial species that requires special attention when determining or verifying the GMRs to ensure it can meet all its life needs and express its natural behaviour in a given area.

Table 1. The size of the home range of red deer (*Cervus elaphus*) in selected European countries and different types of landscapes

Country	The size of the home range	Reference
Bulgaria	7,393 ha	Zlatanova et al. 2019
Germany (Bavarian Alps)	386 ha	Georgii and Schroder 1983
Hungary	9,480 ha	Szemethy et al. 1998
Poland	3,600 ha	Kamler et al. 2008
Slovenia	460 ha	Klemen 2012
Sweden	3,175 ha for stags 1,223 ha for hinds	Jarnemo et al. 2023

Moose are currently protected in Poland (Borowik et al. 2018), fallow deer are non-native and rare species found only in some areas of Poland, while wild boar is subject to separate legislation due to the threat associated with African Swine Fever (Frant et al. 2020, Podgórski et al. 2020), and roe deer, occurs in areas as small as 1–120 ha, primarily in open landscapes (Cederlund 1983, Mysterud 1999, Wasilewski 2001).

The research aimed to develop a method for determining or verifying the boundaries of the existing Game Management Regions in Poland using the example of the Regional Directorate of State Forests (RDSF) in Lublin, based on current, available, and objective criteria.

Material and methods

Study area

The study was conducted in the Regional Directorate of State Forests in Lublin, in eastern Poland (Figure 1). The RDSF covers the entire Lublin Voivodeship and parts of two other voivodeships, managing land with an area of 426,000 ha, of which 408,700 ha is forest land. The geographical, climatic and soil diversity results in habitat types typical for lowland and upland areas within the scope of the RDSF in Lublin. Lowland habitats comprise 92.5%, while upland habitats account for 7.5%. Pine habitats occupy 46.9% of the forested area, and broadleaf habitats cover 45.6%. The share of Scots pine (*Pinus sylvestris*) and European larch (*Larix decidua*) in tree stands is as high as 68.3%, white oak (*Quercus alba*), sycamore (*Acer pseudoplatanus*), common hornbeam (*Carpinus betulus*), Norway maple (*Acer platanoides*) and European ash (*Fraxinus excelsior*) make up 14.1% (RDSF in Lublin 2023).

In 344 hunting districts covering an area of approximately 26,000 km^2, including approximately 7,000 km^2 of forest land, hunting management is carried out by the Polish Hunting Association (332 leased hunting districts and 1 Game Breeding Centre "OHZ-PZŁ"), as well as by the RDSF in 11 excluded hunting districts. Hunting management tasks are executed in leased hunting districts by Hunting Clubs and overseen by forestry offices within the scope of the RDSF in Lublin and the Polish Hunting Association, based on annual hunting plans and long-term hunting plan indicators developed for ten years period for eight GMRs (Figure 1, Table 2) (RDSF in Lublin 2023).

In the area of the RDSF in Lublin, according to the March 2022 inventory, there were 6,500 moose, 14,000 red deer, 800 fallow deer, 65,000 roe deer and 2,000 wild boars. Along with the continuously increasing wildlife population, the amount of damage caused by them in forests is also on the rise. The main causes of the damages are red deer (36%) and roe deer (24%), but moose and beavers are responsible for nearly 40% of the damages (RDSF in Lublin 2023).

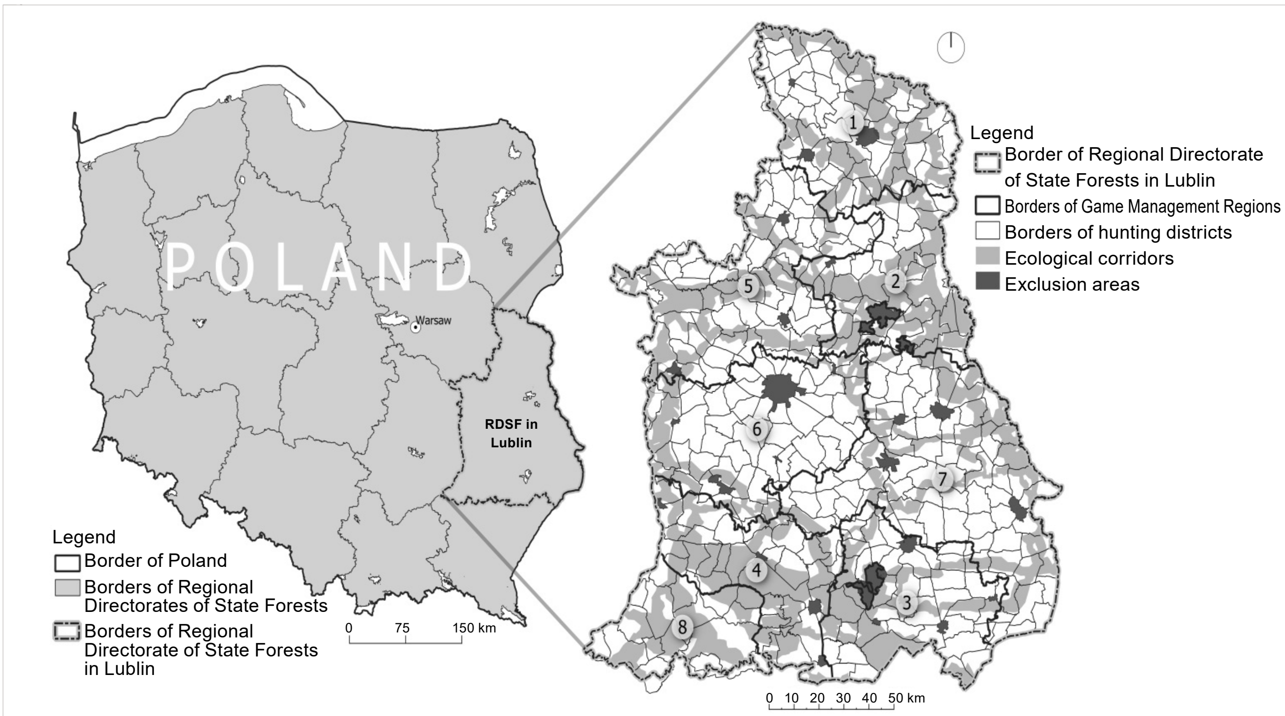

Figure 1. The study area. 1 – GMR Polesie, 2 – GMR Pojezierze Łęczyńsko-Włodawskie, 3 – GMR Roztocze i Puszcza Solsna, 4 – GMR Lasy Janowskie, 5 – GMR Puławsko-Lubartowski, 6 – GMR Lubelski, 7 – GMR Chełmski, 8 – GMR Puszcza Sandomierska (RDSF in Lublin 2023)

Table 2. Data on Game Management Regions operating from 1997 to 2022

No.	Game Management Regions *	Area [km²]	Number of hunting districts entirely contained within the GMRs	Number of hunting districts partially contained within the GMRs
1	Podlasie	3,466.3	60	9
2	Pojezierze Łęczyńsko-Włodawskie	2,541.4	42	25
3	Roztocze i Puszcza Solska	2,973.8	51	22
4	Lasy Janowskie	2,668.6	40	16
5	Puławsko-Lubartowski	4,068.9	69	34
6	Lubelski	3,766.8	60	29
7	Chełmski	5,571.4	85	38
8	Puszcza Sandomierska	1,877.5	17	6

Note: * The ordinal number as shown in Figure 1.

Analysis of the functioning of the GMRs over the last 10 years

We first analysed the functioning of the GMRs over the last decade (ten years). In Poland, each RDSF compiles a long-term hunting management plan, which reflects the current state of the game population (estimated number) in an individual GMRs and the target state (intended number). To achieve this, data provided by the RDSF in Lublin concerning the number, harvesting plan and harvesting results in the years 2012/2013–2022/2023 for red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), fallow deer (*Dama dama*) and moose (*Alces alces*) inhabiting the individual hunting districts included in the existing individual GMRs and the extent of damage caused by these species during the considered period were analysed like in Piekarczyk et al. (2021). The lengths and areas of fences were also assessed. The following were subject to statistical analysis: changes in the cervid populations (moose, red deer, fallow deer, roe deer) (those statuses), total density and forest area, and the implementation of the hunting plan; changes in damage caused by mentioned species; changes in the area and length of fenced plantations; the relationships were analysed between the length and area of the fences used and the extent of damage caused by cervids, as well as the relationship between catching and the extent of damage caused by these animals inhabiting the Lublin RDSF in the seasons 2012/2013–2022/2023. The database was created, and statistical analyses were performed using the STATISTICA 9.1 software package (StatSoft 2009). The distribution of the examined variables was assessed using the Shapiro-Wilk test for normality. Trends were determined using Spearman's rank correlation (R). All relationships were evaluated based on a significance level of $p < 0.05$.

Selection criteria for creating/verifying new GMRs

The second step involved selecting criteria for determining or verifying new GMRs. The analysis considered data from 2012/2013 to 2022/2023 from the RDSF in Lublin regarding the current density of red deer, forest cover, fragmentation of forest patches, categories of hunting districts, as defined in Ministerstwo Środowiska (2019), the routes of existing, under construction and planned highways and expressways (Official Journal of the General Directorate for National Roads and Motorways 2023) and existing ecological corridors (Jędrzejewski et al. 2011).

The boundaries of the GMRs were established through aggregating hunting districts with similar characteristics, considering the course of ecological corridors and barriers, utilising QGIS 3.28 software (QGIS Development Team 2022), while also considering ecological barriers (for example, expressways and residential buildings). The aggregation was performed using geoprocessing tools for vector data, made possible by selecting objects with similar features in the extensive database prepared by the RDSF in Lublin, employing conditional expressions to determine classification criteria for the following features:

1. Red deer population density per 1,000 hectares of forests.
2. Forest cover: the share of forests in the total area expressed as the percentage share of forests to the hunting district area.
3. Hunting district classification prepared by the RDSF.
4. Fragmentation of forest is expressed as the number of forest patches per 1,000 hectares of forest.

For hunting districts within the RDSF in Lublin, four red deer population density classes were determined based on indicators of permissible cervid density on forested areas (Zalewski and Olech 2020). Forest cover was classified into three classes based on data range and expert knowledge from the RDSF in Lublin employees: low – up to 20%, medium – above 20% but not exceeding 40%, and high – above 40% of the hunting district area. The hunting districts classification is an assessment conducted by regional authorities for valuation purposes, following the indicators and factors outlined in the Minister of Environment Regulation of March 12, 2019 (Ministerstwo Środowiska 2019), expressed in five classes: very poor, poor, fair, good, and very good.

Forest fragmentation was classified into four classes, indicating districts with very low or low fragmentation (up to 100 patches per 1,000 hectares of forests) and districts with high and very high fragmentation (above 100 to 500 patches and above 500 patches).

Districts were aggregated in three stages. In the first stage, districts with forest cover above 40%, forest fragmentation below 100 patches/1,000 hectares of forest, red deer population density above 15 individuals/1,000 hectares of forests, and fair or better hunting district categories were selected and grouped. In the second stage, the course and presence of ecological barriers (expressways, highways, and urbanised areas) were analysed, and the previously created groups were divided or merged in a way that the groups of districts with the specified features were located between barriers. Districts meeting at least 2 out of 4 criteria were also grouped. In cases where individual districts without group features were found in the immediate vicinity but constrained by the same barriers, they were included in the respective group. In the third stage, the course of ecological corridors was analysed, and the groups formed in the second stage were divided or merged to ensure that ecological corridors ran through the central part of the group rather than its boundary.

The boundaries of the new GMRs thus constituted the boundaries of aggregated groups of hunting districts.

Results

Step I

Significant increases in the populations of moose and red deer were demonstrated ($R = 0.422$ and $R = 0.248$, respectively, $p < 0.001$), as well as a significant increase in the moose density ($R = 0.438$, $p < 0.001$), red deer density ($R = 0.171$, $p = 0.004$) per 1,000 ha and roe deer density ($R = 0.203$, $p < 0.001$) per 100 ha of the total area. Additionally, there was a significant increase in moose and red deer density per 1,000 ha of forested land ($R = 0.419$ and $R = 0.265$, respectively, $p < 0.001$) despite a simultaneous significant increase in the harvest of red deer ($R = 0.445$, $p < 0.001$) and roe deer ($R = 0.323$, $p < 0.001$) in the Lublin RDSF region during the seasons 2012/2013–2022/2023 (Table 3).

The level of damage caused by cervids (moose, red deer, fallow deer, roe deer) in the studied hunting seasons significantly increased only in the case of damages exceeding 40% caused by moose and red deer ($R = 0.126$, $p = 0.046$ and $R = 0.132$, $p = 0.038$, respectively) (Table 4). Simultaneously, the length of applied fenced plantations ($R = 0.241$, $p < 0.001$) and their surface area ($R = 0.269$, $p < 0.001$) significantly increased (Table 5). Unfortunately, the intended forest protection effects were not achieved through fenced plantations. Although there was a negative correlation between the surface area of damages at the 21–40% level caused by moose, red deer and fallow deer and the length and surface area of fences (while > 40% showed a positive correlation), it was not statistically significant. Satisfactory results in increasing fence length and surface area were demonstrated to significantly reduce damages caused by roe deer at the 21–40% level ($R = –0.211$, $p = 0.001$, $R = –0.215$, $p = 0.001$) (Tables 6 and 7).

It is worth emphasising that executing harvesting plans significantly reduced damages caused by red deer (21–40%, $R = –0.133$, $p = 0.047$), fallow deer (21–40%, $R = –0.294$, $p = 0.029$), and roe deer (21–40%, $R = –0.239$, $p < 0.001$ (Table 8).

During the 2012/2013–2022/2023 seasons, in the Lublin RDSF region the planned and executed harvesting was lower than the actual population growth of these species, increasing in the estimated number and density of red deer (moose are still subject to the hunting moratorium introduced in 2001). Due to the rising populations of cervids (moose, red deer, fallow deer, roe deer), the damages they cause and numerous changes, such as new barriers described in detail in the introduction like fast roads or new developments, there is a need to verify or establish new boundaries for the GMRs within the Lublin RDSF.

Table 3. Trends in cervids' population changes (status), density per total and forested area and plan execution in the Lublin RDSF during 2012/2013–2022/2023

Analysed variable		N	*R*	*p*
Number of big games and years of management	moose	275	0.422	< 0.001 *
	red deer	275	0.248	< 0.001 *
	fallow deer	275	0.089	0.142
	roe deer	275	0.109	0.069
	cervids in total	275	0.441	< 0.001 *
	cervids in total (except moose)	275	0.286	< 0.001 *
Density of animals per total area and years of management	moose [animal/1,000 ha]	275	0.438	< 0.001 *
	red deer [animal/1,000 ha]	275	0.171	0.004 *
	fallow deer [animal/1,000 ha]	275	0.085	0.158
	roe deer [animal/100 ha]	275	0.203	< 0.001 *
	cervids in total	275	0.369	< 0.001 *
	cervids in total (except moose)	275	0.229	0.0001 *
Density of animals per forest area and years of management	moose [animal/1,000 ha]	275	0.419	< 0.001 *
	red deer [animal/1,000 ha]	275	0.265	< 0.001 *
	fallow deer [animal/1,000 ha]	275	0.093	0.123
	roe deer [animal/100 ha]	275	0.088	0.144
	cervids in total	275	0.392	< 0.001 *
	cervids in total (except moose)	275	0.254	< 0.001 *
Shooting and years of management	red deer	250	0.445	< 0.001 *
	fallow deer	249	0.074	0.246
	roe deer	250	0.323	< 0.001 *
	cervids in total (except moose)	250	0.620	< 0.001 *

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Table 4. Trends in the changes in damages caused by cervids in the Lublin RDSF during 2012/2013–2022/2023

Analysed variable		N	*R*	*p*
Damage caused by moose [ha] and years of management	21–40%	250	0.101	0.112
	>40%	250	0.126	0.046*
	in total	250	0.112	0.077
Damage caused by red deer [ha] and years of management	21–40%	250	0.074	0.243
	>40%	250	0.132	0.038*
	in total	250	0.070	0.267
Damage caused by fallow deer [ha] and years of management	21–40%	250	–0.065	0.310
	>40%	250	–0.022	0.728
	in total	250	–0.065	0.307
Damage caused by roe deer [ha] and years of management	21–40%	250	–0.088	0.166
	>40%	250	–0.022	0.725
	in total	250	–0.084	0.184
Damage caused by cervids in total [ha] and years of management	21–40%	250	0.002	0.973
	>40%	250	0.123	0.053
	in total	250	0.029	0.636

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Table 5. Trends in changes in the surface area and length of fenced plantations used in the Lublin RDSF during 2012/2013–2022/2023

Analysed variable	N	*R*	*p*
Total area RDSF in Lublin [ha] and years of management	275	0.000	1.000
Forest area RDSF in Lublin [ha] and years of management	275	0.000	1.000
Afforestation [%] and years of management	275	0.000	1.000
Fence length [m] and years of management	262	0.241	<0.001*
Fence area [ha] and years of management	262	0.269	<0.001*

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Table 6. Relationship between the length of used fences and the extent of damages caused by cervids inhabiting the RDSF in Lublin during 2012/2013–2022/2023

Pair of variables [damages area (m^2) per fence length (m)] and management of year		N	*R*	*p*
Damage caused by moose	21–40 %	238	–0.066	0.313
	> 40%	238	0.004	0.950
	in total	238	–0.049	0.445
Damage caused by red deer	21–40%	238	–0.054	0.406
	> 40%	238	0.013	0.846
	in total	238	–0.068	0.296
Damage caused by fallow deer	21–40%	238	–0.066	0.313
	> 40%	238	–0.022	0.741
	in total	238	–0.067	0.306
Damage caused by roe deer	21–40%	238	–0.211	0.001 *
	> 40%	238	–0.126	0.052
	in total	238	-0.212	0.001*
Damage caused by cervids in total	21-40%	238	-0.169	0.009*
	>40 %	238	-0.054	0.407
	in total	238	-0.159	0.014*

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Table 7. Relationship between the surface area of used fences and the extent of damages caused by cervids inhabiting the Lublin RDSF during 2012/2013–2022/2023

Pair of variables [damages area (ha) per fence area (ha)] and management of year		N	*R*	*p*
Damage caused by moose	21–40 %	238	–0.067	0.303
	> 40%	238	0.008	0.908
	in total	238	–0.047	0.471
Damage caused by red deer	21–40%	238	–0.053	0.416
	> 40%	238	0.029	0.650
	in total	238	–0.064	0.325
Damage caused by fallow deer	21–40%	238	–0.066	0.313
	> 40%	238	–0.021	0.744
	in total	238	–0.067	0.305
Damage caused by roe deer	21–40%	238	–0.215	0.001 *
	> 40%	238	–0.126	0.053
	in total	238	–0.209	0.001 *
Damage caused by cervids in total	21-40%	238	–0.184	0.004 *
	>40 %	238	–0.041	0.530
	in total	238	–0.164	0.011 *

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Table 8. Relationship between the execution of harvesting and the extent of damages caused by cervids inhabiting the Lublin RDSF during 2012/2013–2022/2023

Pair of variables [damages area per soothing] and management of year		N	*R*	*p*
Damage caused by red deer	21–40%	223	–0.133	0.047 *
	> 40%	223	–0.033	0.629
	in total	223	–0.145	0.030 *
Damage caused by fallow deer	21–40%	55	–0.294	0.029 *
	> 40%	55	–0.098	0.477
	in total	55	–0.306	0.023 *
Damage caused by roe deer	21–40%	222	–0.239	< 0.001 *
	> 40%	222	–0.099	0.138
	in total	222	–0.229	< 0.001 *
Damage caused by cervids (except moose)	21–40%	224	–0.325	< 0.001 *
	> 40%	224	–0.084	0.212
	in total	224	–0.295	< 0.001 *

Note: N – the number of hunting districts from which data for statistical analysis, *R* – Spearman's rank correlation, * statistically significant values at $p < 0.05$.

Step II

The analysis aggregated hunting districts with similar characteristics using GIS software and considered ecological barriers and corridors, revealing the necessity of establishing 11 GMRs instead of the current 8. The delineation of their boundaries significantly differed from the previous arrangement. The surface area of the new GMRs varies from 75,020 ha (GMR Nadbużański 8) to 368,300 ha (GMR Zamojsko-Hrubieszowski 9), and they consist of anywhere from 8 to 48 hunting districts (Figures 2 and 3, Table 9).

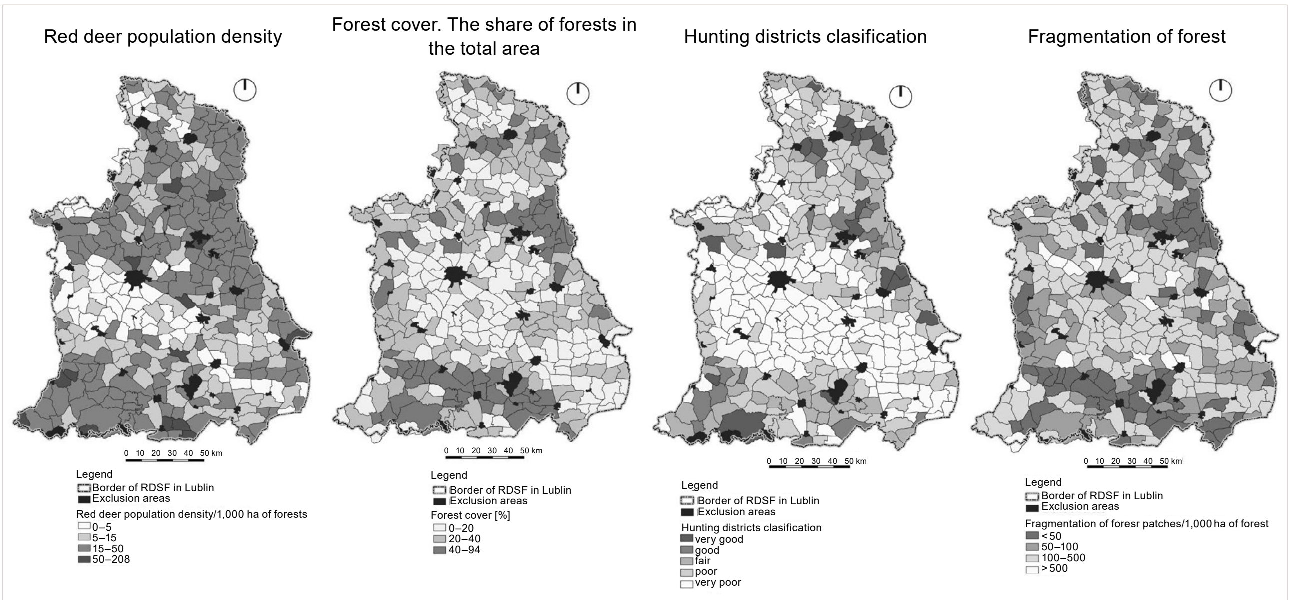

Figure 2. Analysis of red deer population density, forest cover, fragmentation of forest patches, categories of hunting districts

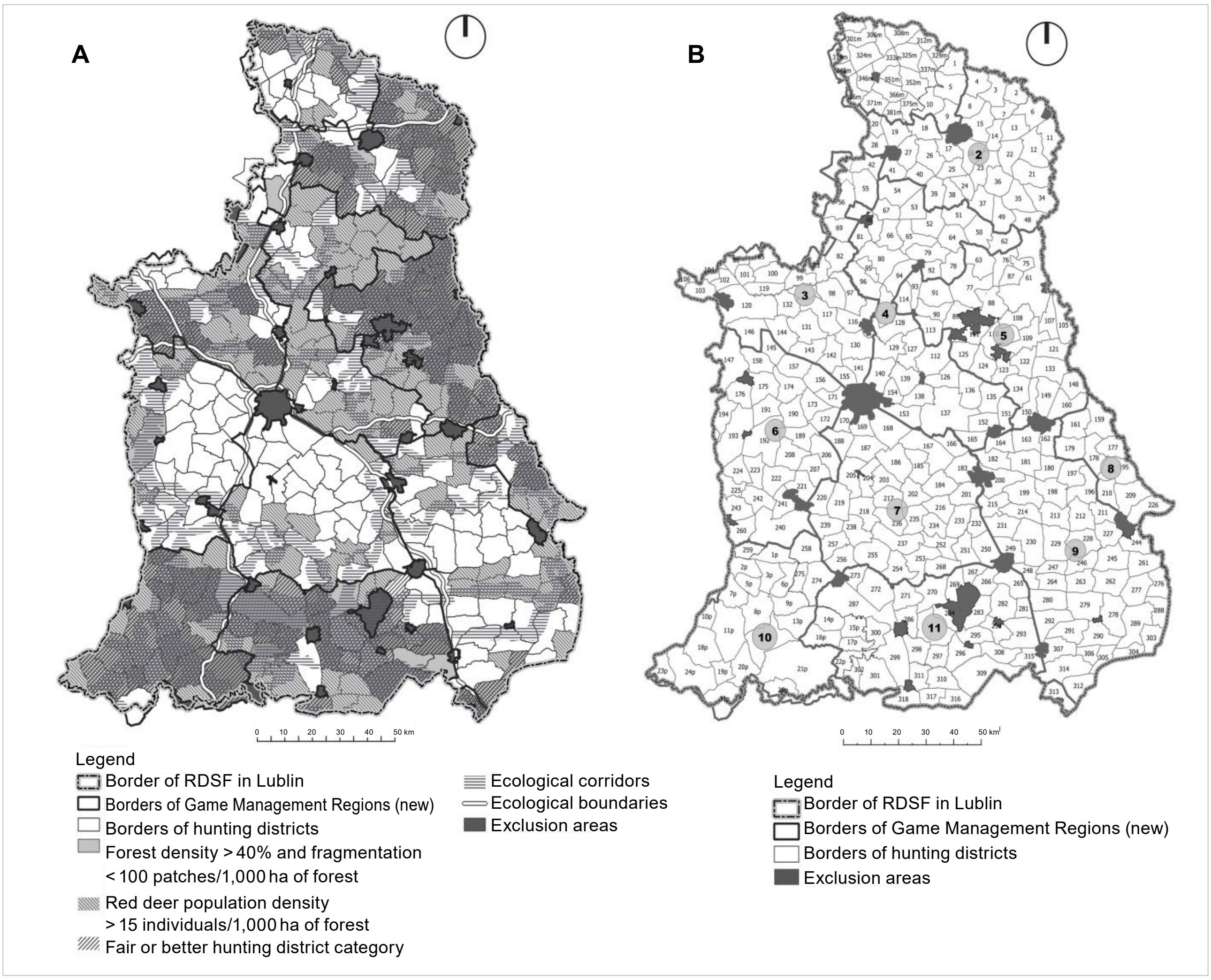

Figure 3. The New Game Management Regions: A) the boundaries of the GMRs in the context of the analysis results, B) hunting districts included in the new GMRs

Table 9. Data regarding the newly determined Game Management Regions

No.	Game Management Regions	Area [km^2]	Number of whole hunting districts
1	Podlaski	1,342.5	24
2	Bialski	2,298.9	34
3	Puławsko-Lubartowski	2,274.9	31
4	Parczewsko-Łęczyński	2,834.9	36
5	Włodawsko-Sobiborski	2,350.0	30
6	Wyżyna Zachodniolubelska	2,536.8	30
7	Lubelski	2,888.0	38
8	Nadbużański	750.2	8
9	Zamojsko-Hrubieszowski	3,683.0	48
10	Puszcza Sandomierska	2,452.0	24
11	Roztocze	2,978.2	39

Discussion

Game management is an integral part of forest management, and game should be an integral component of the forest ecosystem. The responsibilities of foresters and hunters in hunting management include creating optimal living conditions for animals and mitigating conflicts between game animals and human activities (Kamieniarz et al. 2023). By 2022, within the borders of Poland, there were 147 Game Management Regions. Long-term hunting management plans are established for each of them, serving as the basis for adopting breeding strategies. The objective is to achieve the recorded state of the game population after the ten-year plan's validity period. The hunting district system links the right to hunt with land ownership rights and is considered significantly more cost-effective than the licensing system (Fruziński and Pielowski 1992). In Europe, only the hunting district system can be credited with the high population and species diversity of game animals, even in densely populated and industrialized areas of the continent.

Proper game management, especially for flagship species of Central Europe like the red deer, promotes maintenance of the animals at the appropriate density, which in turn prevents competition, reduces the transmission of pathogens and enhances the health and condition of the population (Tajchman and Drozd 2018a, b), which can be achieved through uniform management of large areas composed of numerous smaller ones.

In comparison to other countries, such as Lithuania, where "hunting plot unit must comprise at least 1,000 ha of continuous hunting area..." (FAO/FAOLEX 2002), in the Czech Republic, a hunting guild can establish a fishery if they or with their neighbours have at least 500 ha of continuous land (Mesinger and Ocieczek 2021). In Slovakia, there are 23 state forests, and according to the law, the minimum management area is 1,000 ha for small games and 2,000 ha for big games (Radecki 2015). However, in Hungary, the minimum land area for hunting management purposes is 3,000 ha, where hunting grounds are granted for use by the state regional hunting management administration for 20 years, similar to Poland (FAO/FAOLEX 1997, FAO/FAOLEX 2002, Myronenko 2015). In Germany, private hunting territories (Eigenjagdbezirke) must have a minimum area of at least 75 unbroken ha, and shared hunting territories (gemeinschaftliche Jagdbezirke, pooling together several smaller territories within one administrative district) must have 150 ha. Hunting rights can be leased to third parties, with a limit of 1,000 ha (2,000 in mountain areas) per lessee (Forstner et al. 2006, Myronenko 2015). The acquisition of hunting rights and their relationship to land ownership and the size of hunting units vary greatly in hunting practices across different countries; however, smaller hunting units were listed in each case. This is consistent with the size of the home range, e.g. red deer, but it depends primarily on the available feeding base, the number of hiding places or the density of animals, etc. (Dzięciołowski 1967, Mesinger and Ocieczek 2021).

The described hunting units in individual countries are relatively small areas, corresponding to Polish hunting districts that constitute larger GMRs. Due to the fact that there is no new research on red deer migration, it is worth noting the results of telemetry research on these in Slovakia (with the longest distances being 30, 47 and 65 km). These findings underscore the need to coordinate efforts and objectives in the large-scale management. Almost half of the population migrates, moving across distinct landscape units and farmlands (Kropil et al. 2015). The size of the monthly home precinct determined by the MCP 95% method, reported by Koubek and Hrabě (1996), is in the range of 80 to 440 ha for red deer. Lazo et al. (1994) reported the size of the seasonal home range in winter for red deer to be 1,180 ha. These differences in size are mainly caused by the food supply of the environment and a combination of a whole range of other influences such as the season, age of the individual, sex, weight, and a range of other less significant effects (Mysterud et al. 2000). Overlay of home precincts of various individuals ranged from 18 to 100% (Georgii 1980). Kamler et al. (2007a) published the results of a telemetry study from the Bělověžské práles from the years 2000–2004, which showed red deer home ranges averaging 2,400 ha (1,200–3,800 ha). There are also significant differences between stags and hinds in the size of seasonal home ranges, for red deer an average of 200–400 ha throughout the year; for stags, 700–800 ha in winter and spring, but much larger in summer, 1,300–1,400 ha. Different reproductive strategies mainly cause differences in size of home ranges between the sexes, food availability throughout the year and, last but not least, large predators. Other factors influencing the size of red deer home ranges may also be the density of individuals in a given area, their social behaviour, the degree of competition with other herbivores (breeding cattle), or age (Kamler et al. 2007b).

Like Poland, Slovakia has also changed in its hunting legislation (Act No. 274/2009), establishing large-scale game management for the first time. This involved hierarchical coordination of hunting units in the regions recognised as consolidated hunting areas with identical management objectives. It was proposed that the smallest area subject to uniform management should be at least 300 km^2, considering migration distances of animals. Based on analyses conducted in the Lublin RDSF, it is evident that the area of GMRs should be at least 750 km^2. However, this should be confirmed or verified by detailed telemetry studies on the size of the home range of red deer in individual regions in Poland. This is due to Poland being a significantly larger and more geographically diverse country and it easier uniformly manage of such large units. Moreover, in Poland, there is a spatial information system in the State Forests (Okla 2003). The Computer System of the State Forests (Polish abbreviation SILP) is based on spatial information, primarily the Forest Digital Map (LMN) standard. It covers all management areas in the State Forests (State Forests) National Forest Holding. This system is used by approximately 20,000 users in all organisational units of the State Forests, i.e. in approximately 5,500 forest districts, 430 forest districts, 17 Regional Directorates of the State Forests (RDSF) and General Directorate of State Forests (GDSF). Despite the great dispersion (over the entire country), all State Forests units use uniform software and databases embedded on servers in one data processing centre, which facilitates the coordination of work and management of, e.g. games, even in large spatial units (Okla 2003).

Coordinated efforts at the landscape level aim to prevent conflicting management within the same population. A negative trend can be illustrated by the observed 74% increase in the red deer population in Slovakia from 2000 to 2011, which led to the destruction of young forest stands. This was considered an indicator of conflicting management in the past decade. The authors of the new concept of hunting management regarding damage to young forest stands (Konopka and Kastier 2013) noted that the red deer population 2011 was 57% higher than the standard number, suggesting a gradual reduction in their numbers. Similar observations from the last decade have been noted in the Lublin RDSF, where significant increases in red deer, moose and roe deer populations, and the damage they caused were recorded.

As a result, it is essential to consider the individual home ranges of red deer and adjust harvesting activities accordingly, which appears to be the most effective method for mitigating human-wildlife conflicts and associated damage. An interim, mitigating solution may be supplemental winter feeding, as practised in Slovakia, Ukraine, Lithuania and Romania. However, the impact of supplemental feeding remains unclear, and the results of related studies are often inconclusive (Putman and Staines 2004). Some authors even consider this practice detrimental, leading to significant forest degradation due to browsing (Luccarini et al. 2006). However, experiments with controlled feeding conditions (Rajsky et al. 2008) suggest that properly designed supplemental winter feeding can effectively control wildlife damage. Hanzal et al. (2017) draws attention to the practical problems related to winter feeding, when it is often impossible to ensure the targeted presentation of feed to a specific game species, to comply with the feed dose for core feeds, and pulpy feeds usually freeze. Therefore, he considers the presentation of these feeds to be harmful. On the contrary, he considers it ideal to present high-quality hay, provided that all animals can receive food at the feedlots simultaneously. This will prevent damage to forest stands by unsaturated animals near the places where animals ruminate.

Conclusions

The key to effective big game management primarily involves continuous population monitoring, realised population growth and uniform management across large areas that provide all the ecological needs of big game. Due to the habitat requirements of red deer, special attention should be paid to forest cover, especially its fragmentation, the density of large herbivores, environmental barriers and the ability to move over specific distances through ecological corridors during the creation or verification of Game Management Regions. Our results and the increase in anthropogenic activities in the last period show the need to verify the boundaries of GMRs nationwide.

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