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Tracking population trends: Insights from deer hunting harvests in the Baltics, Central, and Eastern Europe

Ovidiu Ionescu [1, 2], Darius Hardalau[1]*, Mindaugas Bakševičius[3], Michael Manton[4], Dan-Cornel Popovici[1], Codrin Codrean[1], Georgeta Ionescu[2], Daniel Iordache[1]

[1]*Transilvania University of Brasov, Faculty of Silviculture and Forest Engineering, Silviculture Department, No. 1, Sirul Beethoven st., RO-500123 Brasov, Romania*

[2]*National Institute for Research and Development in Forestry Marin Dracea, Wildlife Department, Bulevardul Eroilor 128, RO-077190 Voluntari, Romania*

[3]*Vytautas Magnus University Agriculture Academy, Faculty of Forest Sciences and Ecology, Studentų Str. 11, LT-53361 Akademija, Lithuania*

[4]*Vytautas Magnus University Agriculture Academy, Bioeconomy Research Institute, Studentų Str. 11, LT-53361 Akademija, Lithuania*

Abstract

Understanding the dynamics of ungulates is crucial for proper wildlife management and conservation efforts. Where high densities of ungulates are present and exceed the carrying capacity, damage occurs in both the forestry and agriculture sectors, moreover human safety is endangered through road accidents. This study explores the evolution of deer populations in the Baltics, Central, and Eastern Europe through the analysis of hunting bag data, which represents the total number of specimens harvested annually. By utilizing hunting bag statistics reported by wildlife managers and hunters, this research aims to provide a more reliable indicator for population trends compared to traditional wildlife monitoring techniques, which may suffer from issues such as double counting, underreporting, or different estimation methods. The study focuses on the evolution of hunting bag numbers for red deer (*Cervus elaphus* L.), roe deer (*Capreolus capreolus* L.), and fallow deer (*Dama dama* L.) between 2012 to 2022. The primary metrics used in the description of growth and statistical analyses were the hunting bags and population parameters such as the sex ratio. The findings of this study indicate that hunting bag data have shown an increasing trend during the study period. The sex ratio of the harvested specimens seems to play a role in annual growth only in the case of roe deer. Based on different harvesting rates, the population estimates for the year 2022 were projected. This research confirms similar trends in population growth for the studied species and also indicates an increase in damage caused by high densities of ungulates. The study underscores the significance of integrated approaches in assessing ungulates populations and their ecological roles, contributing to future wildlife management practices.

Key words: roe deer; red deer; fallow deer; population dynamics; wild game management

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1. Introduction

Ungulate population dynamics and distribution are vital for maintaining ecological integrity and balancing human activities such as forestry, agriculture, and wildlife management. Species like red deer (*Cervus elaphus* L.), roe deer (*Capreolus capreolus* L.) and fallow deer (*Dama dama* L.) represent not only important game species but also play key roles in shaping vegetation (Cook-Patton et al. 2014; Pekin et al. 2014), influencing biodiversity (Coulson 1999; Vavra et al. 2007; Adhikari et al. 2021), and serving as prey for large carnivores (Linnel et al. 1997; Clark & Hebblewhite 2021). The three ungulate species are among the most common deer species in Europe, characterized by their extensive range and substantial population numbers.

Red deer has one of the largest distributions, being found not only in Europe but also in Africa, Asia, North

*Corresponding author. Darius Hardalau, e-mail: darius.hardalau@unitbv.ro

and South America. This species is only absent in northern Scandinavia and most of European Russia, being found even in the British Isles and Sardinia (Burbaite & Csányi 2010; Lovari et al. 2019). Out of the studied species, red deer has the biggest body weight and their habitat covers a bigger altitudinal range, being found from the alpine meadows down to the low-land agricultural fields (Szemethy et al. 1998; Cotta et al. 2001). As a polygynous ungulate, (Clutton-Brock & Lonergan 1994) red deer populations not exposed to predation or culling tend to have an adult sex ratio that favors females, typically ranging from 1.5 to 2 females for each male.

Roe deer can be considered the most abundant and widespread species in Europe, except for southern Greece, parts of southern Italy and the Iberian Peninsula, Ireland, Iceland, and some Mediterranean islands such as Corsica, Sardinia, and Sicily (Sommer et al. 2009; Torres et al. 2015). The roe deer is the smallest species, but it is the one best represented by numbers and range (Cotta et al. 2001; Lovari et al. 2017). There is a high inconsistency and variation in the roe deer sex ratio, influenced by various intra- and inter-specific factors, predation, and habitat conditions (Hewison et al. 1999; Vreugdenhil et al. 2007; Macdonald & Johnson 2008).

Fallow deer, originates from Minor Asia, southern Anatolia, Sicily, southern Italy, and the southern Balkan peninsula. It is now one of the most widespread ungulate species in Europe, having been introduced to the majority of the continent (Chapman & Chapman 1980; Ludwig et al. 2012; De Marinis et al. 2022). With a body weight in between those of other studied species, fallow deer is more social than the others (Cotta et al. 2001). In terms of habitat range, fallow deer prefers lower altitude zones and typically does not overlap with roe and red deer, often pushing them outside their habitat (Ferretti et al. 2011). The sex ratio of males to females at birth is about 1 : 1, with very small fluctuations (Ueckemann & Hansen 2002).

Ungulates are influential herbivores that directly affect positively and negatively forest dynamics and plant communities through their browsing activities (Pellerin et al. 2010). Their role as prey species is also critical. Large carnivores like wolves (*Canis lupus* L.) and lynx (*Lynx lynx* L.) depend on ungulate populations for sustenance (Sunde et al. 2000). In regions where predator populations are low or absent due to human intervention, ungulate populations have increased, leading to more significant herbivory pressure on ecosystems (Ripple & Beschta 2012; Beeck Calkoen et al. 2023).

The interaction between ungulate populations and forest regeneration is a central concern for forestry (Ramirez et al. 2018). In many regions, ungulates limit the regeneration of commercially important tree species, such as oak species (Partl et al. 2002; Drexhage & Colin 2003; Cutini et al. 2015), Aceraceae species (Cermak & Mrkva 2006; Fuchs et al. 2021), and especially broad-leaved species (Cermák & Mrkva 2000). In the case of coniferous species, a common issue identified in the literature is the tendency of Silver fir's replacement with Norway spruce through browsing (Heuze et al. 2005; Bernard et al. 2017; Konôpka & Šebeň 2024). Besides browsing, other types of damage, such as bark stripping (Konôpka et al. 2024), fraying, and trampling, are problematic in areas with high ungulate densities. To mitigate ungulate impact, forest managers often employ measures such as controlled hunting. Ungulates are an integral part of hunting culture and rural economy in many parts of Europe (Mysterud et al. 2020). Significant importance should be placed on culling and maintaining an appropriate sex ratio within the adult population. At times, the sex ratio is not well maintained, with the number of females exceeding the number of males, deviating from the ideal ratio of 1 : 1 (Clutton-Brock et al. 2002). The ideal sex ratio for the red, roe and fallow deer is considered to be 1 : 1 (50 : 50), value at which generations do not overlap and mating is strictly at random (Sinclair et al. 2006). Hunting provides a source of income through game tourism, meat production and it also serves as a tool for population control (Apollonio et al. 2010). However, because females are often considered less valuable than males and, as the hunters are reluctant to harvest them, there is greater pressure on males in certain populations (Festa-Bianchet 2003). The selection of ungulates should not be based solely on male harvest; the harvesting of females is equally important. Over time, ungulate populations can become unmanageable, and ungulate overabundance can lead to conflicts with human activities, including forest and crop damages and increased vehicle collisions (Delahay et al. 2007). Thus, understanding the population dynamics and distribution of ungulates is essential for the sustainability of both ecosystems and human livelihood.

This calls for integrated approaches that assess trends in ungulate populations and their distribution. Traditionally, ungulate populations are estimated using various surveying methods conducted by hunters, wildlife managers and relevant ministries, which are then reported at regional or national scales (Done et al. 2024). However, these methods of evaluating large populations can be time-consuming, costly and inaccurate, as the survey area and population numbers may be too large to count efficiently (Daniels 2006; Amos et al. 2014; Davis et al. 2020; Forsyth et al. 2022).The hunting bag method has been proposed and somewhat developed as a timelier and cost-efficient method (Milner et al. 2006; Burbaitė & Csányi 2009; Burbaite & Csányi 2010). By using real data shared by hunters and wildlife managers through different reporting systems based on game tags or licenses, the information can be considered more trustworthy and it can be used even to project the population number estimates. As modern wildlife management is applied, the number of annually harvested game is managed to avoid over-exploitation and to maintain an equilibrium in game populations.

The aim of this study is to evaluate and describe the trends of three European ungulate populations (red deer, roe deer, and fallow deer) between 2012 to 2022, using hunting bag numbers and sex ratios. Firstly, the growth trends of the three ungulate species will be calculated, with 2012 serving as the reference year. Secondly, the correlation between the sex ratio of the harvested specimens and annual growth will be tested. Finally, population numbers for the three species for 2022 will be projected based on three different harvest rate scenarios.

2. Material and methods

2.1. Study area

This study focused on 14 countries from Baltics, Central and Eastern Europe countries. In the Baltics, data were found for all of the three countries: Estonia, Latvia and Lithuania. In the Central Europe region, data were gathered from Germany, Switzerland, Austria, Slovenia, Slovakia, the Czech Republic, Poland, and Hungary; however, data from Liechtenstein were not available. In Eastern Europe, data were collected from Belarus, Romania, Moldova, Serbia and Ukraine, while data from European Russia were not identified. Due to inconsistencies in the data from Moldova, Serbia and Ukraine, these countries were excluded from the study. In the case of Moldova, the numbers were briefly described only for 'hoofed' animals. For Serbia, hunting bag data were reported biennially rather than continuously, and for Ukraine, data were available only for the period from 2018 to 2020. Out of the 14 countries included, sufficient data were available for red and roe deer in all of them. However, Belarus, Slovenia, and Switzerland lacked data for fallow deer. Other areas of Europe were not included in the study due to inconsistent data or because data were not publicly available for all the analyzed years. Including countries where these species are less common or different subspecies are more prevalent would diminish the focus and relevance of the findings. The selected ungulate species are either the most abundant or have experienced significant population increases in recent decades in Baltics, Central and Eastern Europe. Moose was not selected for the study due to their more northern distribution range, and sika deer was excluded because of its reduced range.

2.2. Data collection

This paper proposes an alternative approach to understanding the evolution of deer populations by utilizing the hunting bag. The hunting bag is a parameter that represents the total number of specimens harvested from a species, as reported annually by wildlife managers and hunters. This indicator can be more reliable, as the numbers are reported under specific regulations rather than estimated through various wildlife monitoring techniques (Marrocoli et al. 2019). Although monitoring methods can provide a good statistical representation, they may lead to double counting or to the omission of individuals (e.g., in remote mountainous areas lacking proper infrastructure) (Apollonio et al. 2017). Even though factors such as mortalities caused by deer-vehicle collisions, poaching (Eliason 1999), and predation (Ballard 2003) are important, this paper will focus solely on the hunting bag.

Hunting bag numbers for red, roe, and fallow deer were sourced from national statistical databases and relevant ministries (Table 1). While the accuracy of hunting bag data varies between countries due to differing reporting systems, it is considered more reliable than population estimates. Consequently, hunting bag data provide a more dependable basis for analyzing trends (Carvalho et al. 2024). In order to provide a comprehensive timeline, the study period spanned a decade, from 2012 to 2022, (see Table A1 in Attachment). The final year of investigation was set as 2022, as data for 2023 and 2024 have not been updated for all countries. In most cases, the collected data did not differentiate between sexes and age classes, with the exceptions being Austria, Czech Republic, Romania, and Switzerland.

2.3. Statistical analyses

All analyses will be based solely on the hunting bag and related parameters in order to emphasize its importance and reliability. The database and the visualization were created using Microsoft Excel 16.91. All statistical analyses were performed using IBM SPSS Statistics 29.0.2.0. Firstly, to assess the trend in hunting bag growth for each country, a relative growth trend was calculated based on the provided numbers, with 2012 designated as the reference year. After assessing each country, a map illustrating the overall trend was created, and a general growth trend was established based on the average growth. For the relative growth trend, the difference between the reference year and the following year was divided by the value of the following year (eq. 1):

$$RG1 = \frac{y2013 - y2012}{y2012} \ldots RG10 = \frac{y2022 - y2012}{y2012} \quad [1]$$

where RG = Relative growth;
$y2012$ = the reference of the hunting bag value;
$y2022$ = the value of the hunting bag for the specific year.

Secondly, based on studies by Bijl & Csányi (2022); Cotta et al. (2001), the hunting bag was used as an indicator of population estimates. In this matter, a projection of population size for each country was calculated at dif-

Table 1. Sources of hunting bags in selected countries of the Baltics, Central and Eastern Europe.

Country	Data Source	Comments
Austria	STAT Cube – statistical database of statistics Austria https://www.statistik.at/en/statistics/agriculture-and-forestry/animals-animal-production/hunting	*
Belarus	National Statistical Committee of the Republic of Belarus https://dataportal.belstat.gov.by/osids/rubric-info/1063239	No sufficient data for fallow deer
Czech Republic	Czech Statistical Office https://data.csu.gov.cz/datastat/data/	*
Croatia	Croatian Bureau of Statistics https://web.dzs.hr/default_e.htm	
Estonia	Statistics Estonia https://www.stat.ee/en/find-statistics/statistics-theme/environment	No data for fallow deer
Germany	German Hunter Association (Deutscher Jagdschutzverband) https://www.jagdverband.de/zahlen-fakten/zahlen-zu-jagd-und-jaegern	
Hungary	STADAT- system of Central Statistical Office Hungary https://www.ksh.hu/stadat?lang=hu&theme=kor	
Latvia	Official statistics of Latvia https://stat.gov.lv/en/statistics-themes/environment	No data for fallow deer
Lithuania	Ministry of Environment of the Republic of Lithuania https://am.lrv.lt/lt/	
Poland	Forestry Statistical Yearbook 2022 https://stat.gov.pl/en/topics/agriculture-forestry/	
Romania	Ministry of Environment, Waters and Forests https://www.mmediu.ro/categorie/vanatoare/26	No data for 2012 and 2013*
Slovakia	Statistical Office of the Slovak Republic https://datacube.statistics.sk/	
Slovenia	Slovenian Forest Service https://pxweb.stat.si/SiStat/en/Podrocja/Index/99/environment	No data for fallow deer
Switzerland	Federal Office for the Environment https://www.bafu.admin.ch/bafu/de/home.html	No data for fallow deer*

Note: *Sex and age class data were identified

ferent harvest rates. It is believed that the harvest rate accounts for 20% to 30% of the total population size; values exceeding 30% can lead to over-exploitation of deer species and hinder natural population growth. For this study, the projection was done using 40% harvest rate, as some countries are using even a higher rate in order to keep the ungulate number under control (Burbaitė & Csányi 2009; Burbaite & Csányi 2010).

Thirdly, in order to assess whether the sex ratio of harvested deer impacts the growth of the hunting bag and, indirectly, the overall population size, for harvested deer were available for Austria, Czech Republic, Romania, and Switzerland, the correlation between the sex ratio and the annual growth of the following year was tested using Pearson correlation methods (Bishara & Hittner 2012; Akoglu 2018). It was discovered that Austria, Czech Republic and Switzerland had a ratio closer to 1:1, while Romania had ratios where the numbers of harvested male were higher for both red and roe deer. For the annual growth trend, the difference between the following year and the previous one was divided by the value of the previous year (eq. 2):

$$AG1 = \frac{y2014 - y2013}{y2013} \ldots AG10 = \frac{y2022 - y2021}{y2021} \quad [2]$$

where AG = Annual growth;
$y2013$, $y2014$, $y2021$, $y2022$ = the value of the hunting bag for the specific year.

To enhance the statistical database, data from Austria covering the years 1996 to 2011 were also included, treating the sex ratio and annual growth as independent of country and species.

3. Results

3.1. Relative growth of deer hunting bag in studied countries from Baltics, Central and Eastern Europe

For red deer, the highest relative growth in hunting bags was recorded in Belarus and Lithuania, with an increase of 645.5%, respectively 639.9%. This was followed by Latvia with 330.0%, Estonia at 134.9%, Romania at 129.8%, Slovakia at 122.83%, Croatia at 95.7%, Hungary at 70.0%, Slovenia at 63.8%, Switzerland at 47.6%, and the Czech Republic at 42.4%. In contrast, a decreasing trend was observed in both Austria and Germany, with declines of –2.2% and – 2.0%, respectively. Among three of the studied countries – Estonia, Lithuania, and Romania – the relative value of red deer harvested specimens in 2012 was approximately 1,650. Notably, by 2022, the relative growth rates were 134.9% for Estonia, 129.8% for Romania, and an impressive 639.9% for Lithuania.

Regarding roe deer, Estonia had an impressive growth of 1,232.4%, followed by Latvia with 668.4% and Belarus with 302.7%. Romania and Slovakia also

showed impactful increases, with values of 102.45% and 122.8%, respectively, while Lithuania recorded a growth of 56.9%. Slovenia experienced a decreasing trend of –7.6%, while Switzerland maintained a stable trend at 0.3%. The remaining countries recorded growth values ranging from 3.3% to 25.8%.

Data on fallow deer hunting bags were unavailable for Belarus, Estonia, Latvia, Slovenia, and Switzerland, so relative growth was calculated only for the remaining countries. Aside from Germany, which showed a decreasing trend of –6.2%, all other countries demonstrated an increase in hunting bag numbers. The smallest increase was recorded in Poland at 38.2%, while the other countries reported growth rates above 65%. The highest increase was observed in Lithuania: 1,138.7%, followed by Slovakia at 389.9%, Czech Republic at 135.6%, Romania at 113.4%, Croatia at 111.2%, Hungary at 103.4%, and Austria at 65.7%. The relative growth trend for all of the three cases is presented in Figure 1.

Overall, the population trends of the three species have increased throughout the study area. At Baltics, Central and Eastern Europe level, the highest relative growth in hunting bag values was registered for the fallow deer population (54.1%), followed by red deer with a rise of 50.2% and roe deer with 15.7% (Fig. 2).

3.2. Deer population projections in studied countries from Baltics, Central and Eastern Europe based on the hunting bag

Based on the theoretical projected population size for 2022 across 14 European countries, three harvest rates were used: 40%, 30% and 20%. Based on these projections, the estimated number of red deer ranges from 1,242,600 to 2,485,200 individuals, roe deer population estimate ranges between 5,828,700 to 11,148,000 individuals, while fallow deer population is estimated ranges between 422,700 and 845,300 individuals.

3.3. Sex ratio influence on annual growth for the red deer, roe deer and fallow deer in the studied countries from Baltics, Central and Eastern Europe

In the case of the male and females sex ratio two main situations were identified for both red deer and roe deer. In the case of red deer, for Austria, Czech Republic and Switzerland, the ratio has values between 1 : 0.6

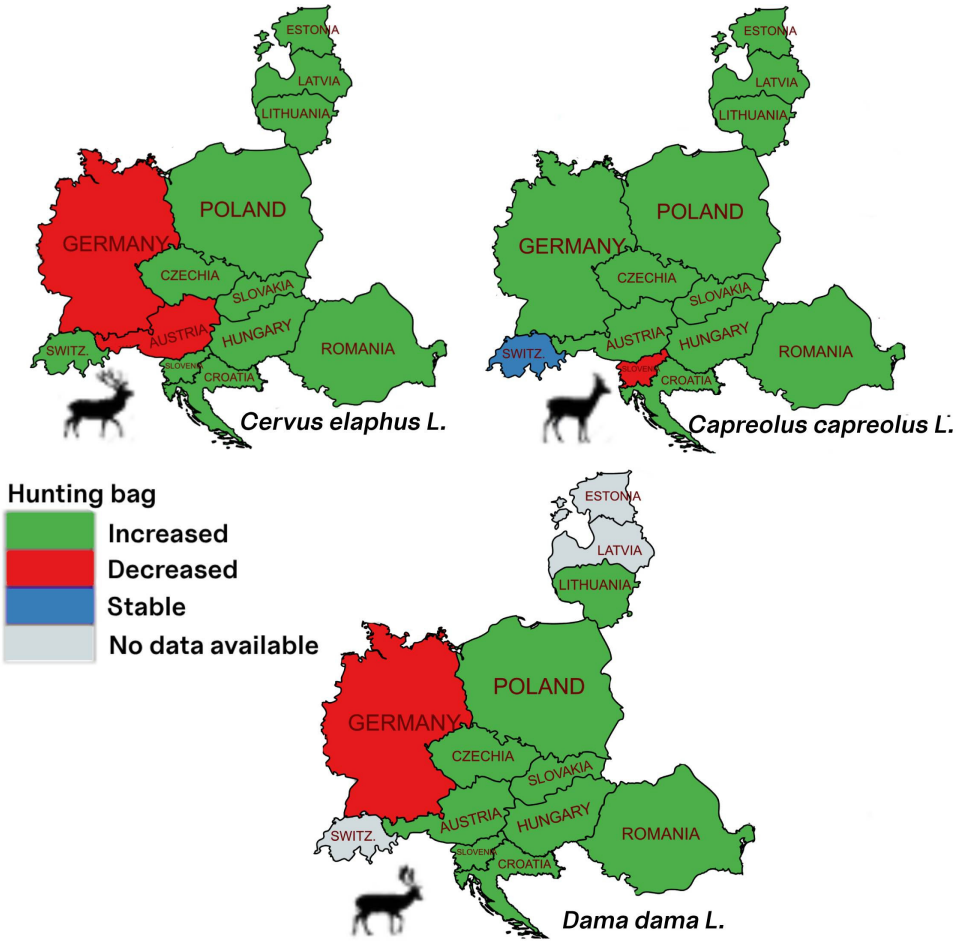

Fig. 1. Changes in deer hunting bags in selected countries of the Baltics, Central and Eastern Europe between 2012 and 2022.

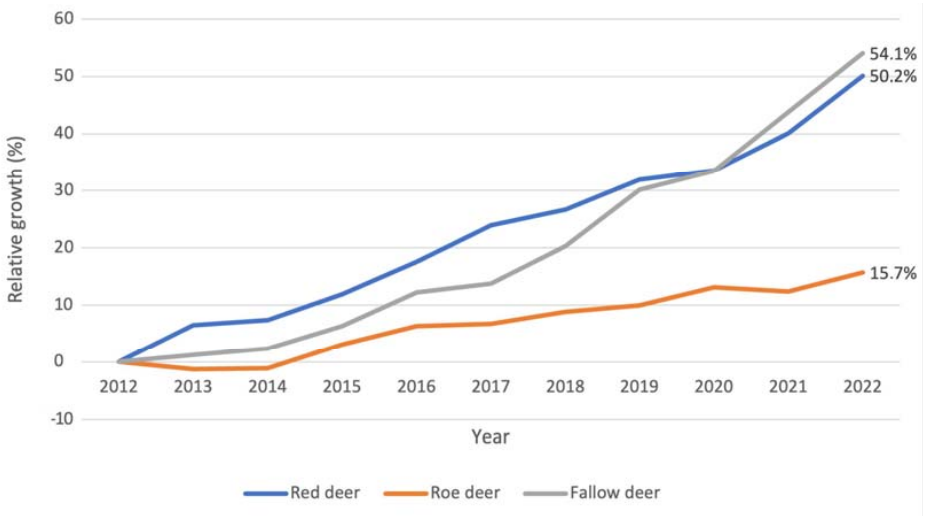

Fig. 2. Relative growth in hunting bags in selected countries from Baltics, Central and Eastern Europe.

Table 2. Population estimation based on adjusted values from hunting bag (thousands) in selected countries from Baltics, Central and Eastern Europe in 2022.

Country	Species								
	Red deer			Roe deer			Fallow deer		
Harvest rate	40%	30%	20%	40%	30%	20%	40%	30%	20%
Austria	144	191	289	728	961	1,456	3	4	6
Belarus	15	20	31	67	88	133	0	0	0
Estonia	82	109	164	285	377	571	0	0	0
Czech Republic	14	18	27	45	59	89	97	128	193
Croatia	16	22	33	103	136	206	4	5	8
Germany	187	247	374	3,264	4,309	6,529	162	214	323
Hungary	203	268	406	274	361	547	52	68	103
Latvia	60	79	120	88	117	177	0	0	0
Lithuania	37	49	74	63	83	126	2	3	5
Poland	269	356	539	505	667	1,010	27	36	54
Romania	12	15	23	71	94	142	4	5	8
Slovakia	146	193	293	146	193	293	75	99	150
Slovenia	22	29	45	77	102	154	0	0	0
Switzerland	34	45	69	113	149	225	0	0	0
Total	1,243	1,640	2,485	5,829	7,694	11,657	423	558	845

and 1 : 1.02, while in Romania, the ratio is reported to be between 1 : 3.3 and 1 : 3.71. For roe deer, in Austria, Czech Republic and Switzerland, the report is between 1 : 1.04 and 1 : 1.44, while in Romania the ratio is above 1 : 3. Similarities can also be found in the case of fallow deer, where Austria, Czech Republic and Switzerland have ratios between 1 : 0.62 and 1 : 1.14. In Romania the fallow deer sex ratio is between 1 : 1.85 and 2:44. Based on this number, it can be admitted that Romania has an approach where the culling is done mainly on males. In the other studied countries, an emphasis is put also on the female harvesting. The values of annual growth are varying greatly in all of the countries with values for red deer between –14.2% and 42.4%, for roe deer between –7.9% and 26.3% and for fallow deer between –20.1% and 66.2%.

According to the results of the statistical analysis, the sex ratio of harvested specimens does not significantly influence population growth in the following year for red deer and fallow deer, as indicated by all three statistical analyses (Table 3). However, for roe deer, the sex ratio has a significant impact on the annual growth in the subsequent year. A higher proportion of harvested males correlates with a moderate increase in the annual growth of roe deer (Figure 3), which explains a higher annual growth of roe deer in Romania compared to the other countries.

Table 3. Pearson correlation rank coefficients (r) and the significance levels (P) for the sex ratio of harvested specimens and the population annual growth.

Species	Statistical test	
	Pearson correlation (r)	Significance levels (P)
Red deer	–.004	.978
Roe deer	.594**	<.001
Fallow deer	–.152	.317

Note: **Correlation is significant at the 0.01 level (2-tailed).

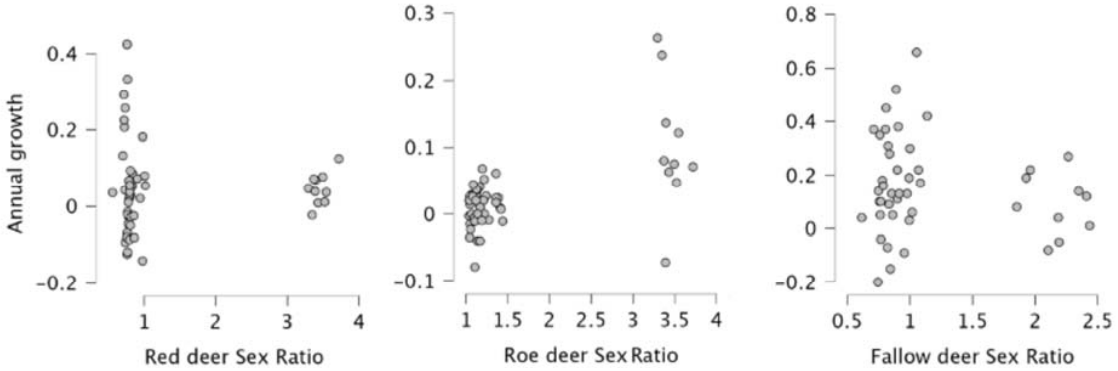

Fig. 3. The distribution of correlation points of sex ratio of harvested specimens and population annual growth based on the Pearson analysis

4. Discussion

Based on the findings of this study, all three species have shown an increasing trend in hunting bag growth. This harvest increase in harvest suggests a corresponding growth in population. In Romania, all three species have demonstrated an upward trend during the studied period, primarily attributed to the adoption of a modern wildlife management plan that emphasizes normalizing both population numbers and sex ratios. Since the 2010s, the management of hunting grounds has been assigned to private managers, forest administrators, and county associations, following strict regulations, harvesting plans, and monitoring techniques. Additionally, due to the high density of large carnivores, red deer and roe deer have migrated to lower altitudes and in the proximity of agricultural crops, where they have begun to reach abundant densities (Hardalau et al. 2025).

The highest overall growth has been recorded for the fallow deer, with an increase of 54.1%. This species has been anthropogenically influenced in its distribution and it is one of the world's most widely naturalized animals, aside from domesticated or feral livestock (Esattore et al. 2022). The highest growth was identified in Lithuania with an increase of 1,138.7%. This growth can be explained by the efforts of creating a stable population of fallow deer in Lithuania. The second highest growth was identified in Slovakia, with an increase of 389.9%, followed by the Czech Republic with 164.9%. These increases are primarily attributed to management efforts driven by the popularity of fallow deer as a game species in these countries, as well as the escape of fallow deer from farms.

Red deer has become one of the most proficient species in recent decades, with an overall growth of 50,2% in hunting bags, as their populations have increased in most of the studied countries, except for Austria and Germany. Particularly in Germany, the population of red deer is already oversaturated, and efforts to reduce their numbers have been a long-standing concern for hunters in order to prevent damage to forestry and agriculture (Hothorn & Müller 2010; Gerner et al. 2011; Heinze et al. 2011). As the trend in Germany and Austria shows a decrease in red deer populations, it can be stated that these countries are managing the issue effectively. In both Belarus and Lithuania the hunting bag increased drastically, with more than 600% in the studied period. In the case of Belarus, the adoption of modern hunting management and a proper monitoring method made the red deer and roe deer population explode (Shumski et al. 2017). In Lithuania, the growth and high densities of red deer are primarily due to immigration and relocations following World War II, particularly after the adoption of proper management plans in the 2000s and the increase in final forest harvesting, resulting in a greater availabity of young stands for foraging (Balčiauskas & Kawata 2022). In the last five years, the red deer population in Lithuania has doubled, leading to increased damage to agricultural crops and forests, which resulted in the lifting of the hunting quota for red deer (Bakševičius unpublished). The 330% growth of the red deer population in Latvia can be primarily attributed to the reintroduction efforts in the 19th century and forest management (Baumanis et al. 2018). Since then, the red deer population has undergone impressive changes, allowing it to occupy nearly 90% of the country's territory and follow a normal population development pattern.

Among the three studied species, the roe deer recorded the lowest relative growth value in hunting bags; however, the overall harvest numbers are nearly five times higher than those of red deer. During the decade from 2012 to 2022, the highest growth rates were observed in Estonia and Latvia, with impressive increases of 1,232.3% and 668.4%, respectively. The newly adopted hunting regulations and quotas, along with milder winters, lower predatory pressure, and an increase in agricultural crops, have created more favorable conditions for the roe deer population to thrive (Burbaitė & Csányi

2009). The growth of roe deer in Lithuania over the past two decades has made it the most abundant ungulate species, outnumbering moose by 8 to 12-times and red deer by 2 to 4-times (Balčiauskas 2024).

Not only have hunting bag numbers increased in the past decades, but population numbers have also risen exponentially. Based on the population projections made in this study, a similarity was identified in the same countries compared to other studies conducted prior to this one. In the case of red deer, considering the lowest population estimate of 1,243,000 individuals, these figures are approximately three-times higher than those reported by Burbaite & Csányi (2010) for the year 1984 and 2.2-times higher than the values from the 2010s for the same countries. For roe deer, compared to a similar study conducted by Burbaitė & Csányi (2009), the lowest estimate of 5,829,000 individuals is 1.82-times higher than the value reported in 1984 and 1.31-times higher than the value from the 2000s. For fallow deer, the lowest estimate from the projection is 423,000 individuals, which is only 15% higher than the population reported by Bijl & Csányi (2022) at the beginning of the 2020s, corresponding to a growth of around 7.5% each year in fallow deer numbers.

Based on the correlation analysis, it was found that only in the case of roe deer does the sex ratio of harvested specimens impact annual growth, while for the other studied species, these parameters did not show any correlation. In many deer populations, the main goal of management is to optimize the annual harvest of mature males. This requires a high culling rate of females to prevent their numbers from increasing to a point that negatively impacts male survival and skews the adult sex ratio in favor of females (Clutton-Brock & Lonergan 1994). These findings may be explained by the ethology of the species and the age at which they reach adulthood and are able to reproduce (Cotta et al. 2001). As the roe deer is the smallest of the studied species and has the lowest age of reaching adulthood, it might explain the existing correlation. However, other studies have shown that at high densities of red deer, the tendency of dominant females to give birth predominantly to males disappears, resulting in a ratio that favors females (Kruuk et al. 1999). The significant increases in all three deer populations may be influenced more by other factors than the sex ratio of harvested animals. These factors include advancements in agricultural and forestry technology, improvements in crop genetics, greater forage availability in forested areas and low large carnivores densities (Apollonio et al. 2010; Kaczensky et al. 2013; Reimoser & Reimoser 2016; Bijl & Csányi 2022). In some cases, such as in Poland and Romania, where a large and stable population of large carnivores is present, it must be acknowledged that, in addition to the hunting bag, a considerable number of deer are naturally removed by carnivores (Kaczensky et al. 2013; Chapron et al. 2014).

Ungulate overabundance is affecting the forestry, agricultural and the human safety itself. High ungulate densities can lead to over-browsing, which reduces tree seedling survival, alters species composition, and impedes tree recruitment (Gill 1992; Angelstam et al. 2017). Over-browsing often impacts overall plant diversity and habitat quality which results in a shift towards less palatable species (Bernes et al. 2018), which are not always the species desired by forest managers. Timber depreciation caused by browsing, bark stripping, and fraying also impacts the financial gains of forest managers (Ichim 1989; Gill 1992), particularly in areas where timber production is a key industry (Suzuki et al. 2021). A study from Slovakia has shown that artificially regenerated tree stands are more susceptible to browsing than naturally regenerated ones (Šebeň & Konôpka 2024). In the case of the stands with natural regeneration, the sapling density is considerable higher and the damaged saplings are considered "compensatory mortality" (Reimoser & Gossow 1996). Additionally, the opening of new forest gaps allows pioneer species to install, such as rowan (*Sorbus aucuparia* L.), aspen (*Populus tremula* L.) or blackberries (*Rubus hirtus* Waldst. & Kit.) (Edenius & Ericsson 2015; Konôpka et al. 2018). In some cases, such as Austria, the damages caused by ungulates to the forestry sector reached up to 218 million euros annually between 1990 and 1999 (Reimoser & Reimoser 2010). In the case of damages in agricultural fields, ungulates primarily affect corn and wheat crops, reducing their yield per hectare (Bleier et al. 2017). Additionally, by trampling, they decrease the height of the plants and indirectly the productivity of the plant (Drimaj et al. 2023). In the case of road accidents involving ungulates, the number of incidents has surpassed millions worldwide, with damages exceeding billions of euros through various compensation methods (Langbein et al. 2011).

Currently, the focus of wildlife management is not on increasing population sizes but rather on maintaining and reducing the numbers (Barton et al. 2022). The carrying capacity is a crucial indicator that should be highly respected (Monte-Luna et al. 2004). Three main aspects of this parameter (ecosystem, economy and social acceptance), which influence the coexistence between ungulates and humans, should be considered for effective wildlife management (Linnell et al. 2020). Wildlife managers should maintain ungulate populations at levels that do not exceed the ecosystem support capacity, as excessive populations can negatively alter the ecosystem (Apollonio et al. 2017). Ungulates and other game animals must be maintained at levels that do not cause more damage than forest managers, wildlife managers, or ministries can support (Reimoser & Putman 2011). Social acceptance must be considered, as a high number of ungulates can create problems for local communities and farmers, problems that they may not be willing to tolerate (Carpio et al. 2024). In response, these com-

munities might resort to alternative methods to reduce ungulate populations on their own.

The countries involved in this study employ various methods to establish the limits of game that can be supported by the ecosystem, the economy, humans, or a combination of these factors. In the case of Romania, the Ministry of Environment, Waters, and Forests has established an optimal population number for game that should be maintained based on the characteristics of certain areas. According to Almasan H. (1988), the method establishes the limits that can be supported by 1,000 hectares of forest, depending on various richness types. Additionally, based on the body mass of the ungulates and on the consumption level, the study proposed that the stock unit equivalents for deer are as follows: for every 5 roe deer, the equivalent is 1 red deer, and for every 1.78 fallow deer, the equivalent is also 1 red deer. Similarly, Ministry of Environment of the Republic of Lithuania , has set limits of animals per 1,000 ha based on the forest type. In this case, for every 4 roe deer, the equivalent is 1 red deer. In both of the cases, the stock unit equivalent should not exceed the limits of the carrying capacity. As most ungulates coexist in the same areas, a stock unit equivalent based on the carrying capacity should be proposed throughout Europe to ensure that ungulate populations remain under control. By reducing the number of ungulates to levels that can be supported ecologically, economically and socially, the damages they cause can also be kept at acceptable levels. In order to control the increasing growth of ungulate populations, new management practices that promote culling and the reintroduction of large carnivores should be implemented. At European level, a uniform method for game estimation and a hunting bag reporting system should be established. Additionally, there is a need for the harmonization of the interests of hunters, foresters, and farmers, which requires a coordinated approach across EU countries.

While this study utilized harmonized data, it does have limitations stemming from the variations in wildlife management practices across Europe. Our conceptual model was applied solely to the hunting bag and related parameters. Wildlife management varies significantly among the selected countries, with the size of the hunting grounds being a key issue (Mesinger & Ocieczek 2021). These grounds can range from private properties of just a few hectares to leased hunting areas as large as 30,000 hectares, and data on this variability were not available. Additionally, the terrain's orography plays an important role; some hunting grounds are located in remote mountainous areas, which cannot be managed as effectively as those situated in flat regions. The densities of large carnivores and the effects of natural selection were not taken into account (Linnell et al. 2001). Future studies should also focus on the impact of both large and small carnivores, as well as the losses due to mortality and competition with livestock. Additionally, similar studies should be developed on moose, sika deer, wild boar and other species of interest. The impact of ungulates is a significant issue for ecosystems, economics, and human safety, and more emphasis should be placed on this subject.

5. Conclusion

This study focused on the growing of the ungulate population across 14 countries from Baltics, Central and Eastern Europe, a phenomenon of a high interest for practitioners and academics. The approach of quantifying the growth was the use of hunting bags as a primary parameter. Evidence from previous studies confirms the robust growth of ungulate population based on hunting bags in the 2012–2022 period. Despite the harmonized data used in the study, limitations exist due to varying wildlife management practices across different countries, as well as the influence of terrain and large carnivores' presence. Future studies should focus on these factors to develop a more nuanced understanding of ungulate dynamics.

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Attachment

Table A1. Deer hunting bags in 2012–2022 period in studied countries from Baltics, Central and Eastern Europe.

Red deer hunting bags in 2012–2022 period											
Country	Year										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Austria	59,034	58,138	51,677	52,024	53,458	61,545	54,977	57,524	54,240	56,294	57,736
Belarus	826	893	1,149	1,157	1,508	1,661	2,031	2,590	3,149	4,213	6,158
Czech Republic	23,092	23,578	23,361	23,978	26,152	27,878	28,287	29,017	29,842	30,792	32,884
Croatia	2,784	2,982	3,355	3,219	3,305	3,350	2,944	4,112	4,398	5,073	5,449
Estonia	1,658	2,094	2,088	2,504	3,328	3,832	5,514	5,086	5,164	6,390	6,540
Germany	76,391	75,773	74,359	78,596	79,132	76,794	77,182	76,897	76,458	75,667	74,841
Hungary	47,700	53,100	53,700	53,600	55,100	58,100	65,000	66,500	65,600	76,200	81,100
Latvia	5,606	7,578	8,735	9,774	11,805	13,736	15,330	17,825	20,039	20,524	24,047
Lithuania	1,620	2,476	3,204	3,857	5,266	6,405	7,876	8,968	9,048	12,472	14,797
Poland	68,928	77,564	83,536	89,333	93,497	94,359	95,365	98,877	102,776	100,461	107,728
Romania	1,617	1,900	2,160	2,605	2,753	2,670	3,212	3,549	3,865	4,198	4,596
Slovakia	26,261	30,650	31,493	31,988	35,268	38,365	42,937	45,320	46,052	49,558	58,518
Slovenia	5,431	4,971	5,816	6,064	6,591	7,425	6,484	7,151	7,339	8,856	8,896
Switzerland	9,174	10,521	10,715	11,657	11,904	14,075	12,081	13,043	14,000	12,851	13,543
Roe deer hunting bags in 2012–2022 period											
Country	Year										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Austria	282,102	272,268	268,054	276,222	280,036	285,718	284,916	278,312	285,610	285,599	291,289
Belarus	6,614	6,223	6,615	7,880	9,323	11,098	12,371	15,668	16,472	22,495	26,633
Czech Republic	108,591	105,680	100,348	99,828	100,834	103,455	102,229	103,018	105,570	107,433	114,100
Croatia	14,211	15,235	16,800	16,397	15,023	15,400	16,160	16,691	17,789	17,957	17,879
Estonia	3,096	5,768	8,144	12,519	22,000	31,614	48,292	62,064	51,556	49,504	41,246
Germany	1,192,583	1,152,565	1,139,536	1,188,066	1,214,458	1,190,724	1,206,996	1,226,169	1,285,562	1,276,355	1,305,758
Hungary	96,300	100,400	111,500	114,500	113,700	113,600	119,300	115,500	108,700	111,500	109,400
Latvia	4,600	7,028	5,870	9,362	13,170	17,319	22,135	27,422	34,854	37,730	35,344
Lithuania	16,000	16,763	16,319	21,294	23,828	26,592	28,931	31,564	23,650	26,206	25,107
Poland	172,941	187,371	195,777	203,355	213,518	214,769	210,133	192,850	202,738	177,348	202,007
Romania	11,470	13,698	16,050	17,956	21,644	22,531	23,182	24,882	23,878	27,214	28,335
Slovakia	26,261	30,650	31,493	31,988	35,268	38,365	42,937	45,320	46,052	49,558	58,518
Slovenia	33,382	31,144	33,219	33,668	33,918	34,156	30,875	31,856	31,088	31,128	30,852
Switzerland	42,525	42,326	40,818	42,623	43,643	44,394	42,667	42,653	43,206	43,418	43,545
Fallow deer hunting bags in 2012–2022 period											
Country	Year										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Austria	712	807	930	805	870	870	909	1,034	980	1,083	1,180
Czech Republic	14,591	16,404	16,761	18,968	20,402	23,069	23,800	28,978	30,982	33,250	38,653
Croatia	753	807	1,021	897	934	880	971	1,104	1,228	1,261	1,590
Germany	68,980	64,113	62,521	65,176	64,895	63,103	65,427	68,211	66,547	68,269	64,687
Hungary	10,100	12,300	13,900	11,600	14,300	13,700	15,900	16,600	16,900	19,200	20,600
Lithuania	75	114	146	193	278	377	444	508	506	767	929
Poland	7,792	8,651	8,959	9,649	10,001	9,464	9,013	8,664	10,049	10,117	10,769
Romania	457	628	851	1,009	1,150	1,290	1,300	1,645	1,516	1,580	1,494
Slovakia	6,141	7,261	7,405	8,558	10,593	12,439	14,677	16,597	18,245	23,024	30,082