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Population dynamics of Grey Partridge (*Perdix perdix*) in Sakar Mountain over 15 years

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Abstract. The population dynamics of the Grey Partridge were monitored over a 15-year period. Breeding density and brood size were investigated, and statistical relationships between breeding density, brood size, and density – related losses were analyzed. The average breeding density for the entire study period was 1.5±1.83 (0-12) pairs/100ha. The average brood size was 10.26±4.84 (2-21) individuals. Autumn-winter losses varied from 2.3% to 15.8%, showing a decreasing trend from 2018 to 2023. Spring-summer losses averaged 51.5%. The results indicate a slight increase in the breeding density of Grey Partridges in the Sakar Mountains over the past 15 years. However, the species' density remains lower compared to other plain areas of the country, likely due to differences in habitat quality.

Key words: breeding density, brood size, losses, population trend.

Introduction

The Grey Partridge (*Perdix perdix*) is a common species found on arable land across much of Europe. However, its population experienced a drastic decline after the end of the Second World War (Aebischer & Kavanagh 1997, Kuijper *et al.* 2009, Aebischer & Ewald 2012), a trend that continues to this day (Birdlife International 2022, Keller *et al.* 2020). This species has been extensively studied across its range, and thus, conservation measures are generally well-understood. Research suggests that intensive agriculture and the widespread use of pesticides are the primary drivers behind the species' decline in recent decades, with corresponding conservation efforts aimed at mitigating these factors (Potts 1986, Potts & Aebischer 1995, Benton *et al.* 2003, Kruijper *et al.* 2009, Ronnenberg *et al.* 2016).

In Bulgaria, the Grey Partridge is considered abundant in regions such as Dobrudzha, the Danube Plain, and around the cities of Stara Zagora, Sliven and Burgas. However, a significant decline in the species occurred in the Danube Plain during the mid-20th century (Boev & Konstantinov 1954). Up until the end of the 1980s, the species exhibited stable population trends nationwide (Patev 1950, Nankinov *et al.* 2004, Iankov 2007), with sharp fluctuations linked to epizootics or extreme weather events (Boev & Konstantinov 1954, Botev 1962). Between 2018 and 2020, the average breeding density in the Thracian Lowland was recorded at 6.27±4.73 SD (range 0-20 pairs/km^2) (Angelov 2022). From 2007 to 2018, the Grey Partridge density in the Sakar region averaged 1.23±0.19 (min-max 1-1.53 pairs/km^2). Notably, positive correlations were found between brood size and the number of rainy days in July, as well as the area of sunflower crops in the Sakar (Gruychev & Angelov 2019).

The Sakar Mountains are characterized by a continental Mediterranean climate with relatively high average annual temperatures (Kopralev 2002). The area's open habitats consist of arable land, pastures, and secondary vegetation (Bondev 1991), creating a mosaic of environments that support the Grey Partridge. Despite this, previous studies have shown a significantly lower breeding density of the species in Sakar compared to the Thracian Lowland (Gruychev & Angelov 2019, Angelov 2022). The ornithofauna of the Sakar Mountain includes 253 bird species, making it one of Bulgaria's most important and biodiverse bird areas (Stoychev *et al.* 2008). Recent studies in northwestern Sakar have reported the addition of 7 new species, and breeding density has been documented for 13 others (Gruychev 2021).

The aim of this study is to provide additional data on the Grey Partridge population in the Sakar Mountains, thereby enhancing existing knowledge about the species and highlighting potential future threats.

Material and Methods

Study area

Sakar is a low mountain range in Southeastern Bulgaria, bordered by the rivers Maritsa, Sazliyka, Tundzha, and Sinapovska (Stoychev *et al.* 2008). The terrain is hilly and gently folded, and the climate is Continental-Mediterranean. The average annual temperature ranges between 8° and 13.5° C. Annual rainfall is between 500-900 mm, with winter maximum and a summer autumn minimum (Kopralev 2002). The natural vegetation consist of xerothermic oak forest, which have been largely replaced by arable land and secondary vegetation, including Christ Thorn (*Paliurus spina-christi* Mill.) mixed with Jasminum (*Jasminum fruticans* L.) and xerothermic grass formations dominated by Belize (*Dichantieta ischaemi*) (Bondev 1991). Cultivable lands are predominantly small areas of various agricultural crops, with large monoculture fields covering less than 10% of the total arable land in the region. The main agricultural crops include wheat, barley, triticale, sunflower, sorghum and canola. Permanent plantings primarily consist of vineyards and small orchards, including walnuts, almonds, and pears. Many small artificial water sources were constructed in the past for irrigation purposes, although a large proportion of them have since dried up and no longer exist. A portion of the study area is located within the Natura 2000 ecological network. It encompasses three zones (BG0002020, BG0002021, and BG0000212), two of which are designated for the protection of bird species, while the third focuses on the conservation of particular habitat types.

Field methods

We used a transect points' method to determine the breeding density, with censuses conducted along the same transects surveyed between 2007 and 2018 (Gruychev & Angelov 2019). This approach ensured comparability of data across the 18-year study period. A total of 24 transects were studied across 22 hunting areas (see also Gruychev & Angelov 2019, Gruychev 2024). Breeding density was determined by linear transects and the recording of male partridge calls during the March-May period (Gruychev & Angelov 2019). To improve the detectability of males, a mating song was played every 200 meters along each transect. Observers conducted 10-minute count surveys at each point. All surveys were performed in calm weather, without precipitation, between 4:30 AM and 9:00 AM, and between 5:00 PM and 6:30 PM. Each transect was visited twice during the period from March to May. From July to September, brood size and the number of successful breeding pairs were re-estimated along the same transects. A pair of dogs (a German wirehaired pointer and an Akita Inu) was used in each transect to minimize the likelihood of errors from July to September. This method is suitable for species that are easily identifiable, mobile, and occur at low densities (Bibby *et al.* 1998). The average length of transects was 3.96 ± 1.73 (1.5 – 7 km), and a strip width of 100 m (Gruychev & Angelov 2019). This width corresponds to the average distance between the observer and the dog, as well as the distance reached by the sound from the playback device.

Breeding density was determined by the maximum number of pairs observed in each transect during March – May, and the data were subsequently calculated for an area of 1 km2 (Bibby *et al.* 1998). The average brood size was calculated as the number of fledglings per adult pair. In cases where only one adult bird was observed, the number of the fledglings was calculated per adult pair, considering only successfully breeding pairs.

From 2018 to 2023, we also tracked the losses of partridges during the spring and autumn-winter periods. Spring losses were calculated as a percentage of the species spring density. For this calculation, the number of adult pairs was also determined in summer (July - August), when the young were still distinguishable from adults. During this period, we calculated the percentage of loss among adult individuals. In addition to losses, this category included individuals that left the study areas and could not be accounted for. We assume that losses in autumn and winter were primarily due to mortality in the flocks. Losses during the autumn-winter period were tracked from October to February of the following year. These losses were determined by monitoring the number of birds in flocks every 2-3 weeks along the same transects where breeding density was assessed. The losses were recorded in part of the transect areas near the villages of Balgarin, Rogozinovo, Dositeevo, and Ovcharovo (a total 10 transects).

Statistical methods

We used Pearson's product-moment correlation to test the relationship between breeding density and brood size. The same method was applied to examine the relationship between breeding density and losses during the spring-summer period, as well as brood size and autumn-winter losses. Differences in breeding density and brood size across years were tested using One-Way Anova. All statistical procedures were performed using PAST (Hammer *et al.* 2001).

Results

The average breeding density throughout the study period was 1.5±1.83 (0-12) pairs/100ha (mean±SD- min-max). Breeding density exhibited fluctuations with alternating peaks and declines occurring approximately every 3-4 years (F=2.265, df=14, p=0.006) (Fig. 1). Over the course of study, an increasing trend in breeding density was observed.

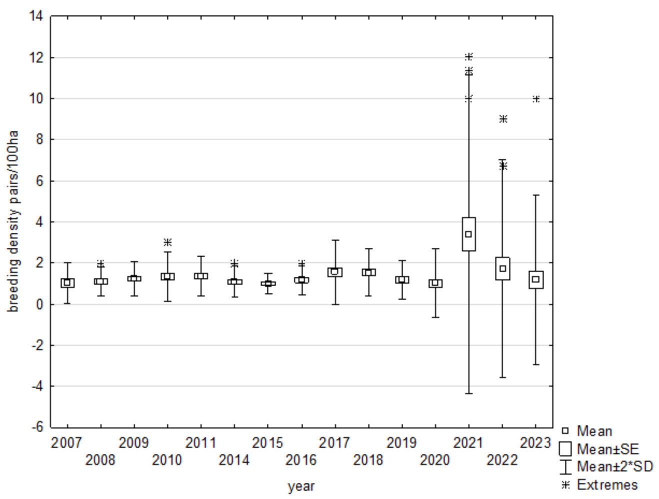

Fig. 1. Dynamics of breeding density of Grey Partridge (*Perdix perdix*) between 2007-2023 years.

The average brood size over the entire study period was 10.26±4.84 individuals (min-max: 2-21; mean±SD). Statistically significant fluctuations in mean brood size were also observed between years, with the peaks occurring over a longer period compared to breeding density (F=5.492, df=14, p<0.0001) (Fig. 2).

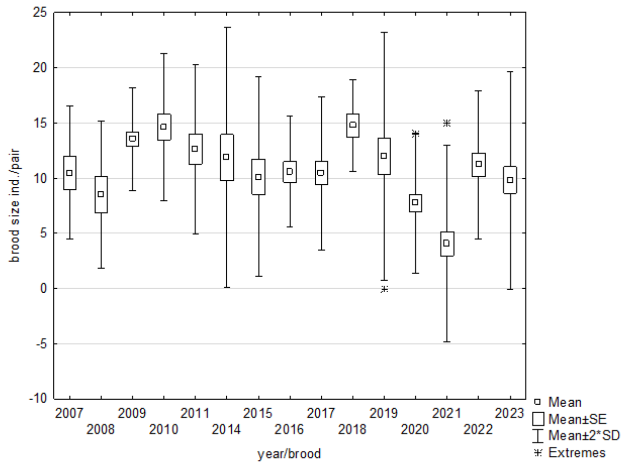

Fig. 2. Dynamics of average brood size of Grey Partridge (*Perdix perdix*) in Sakar Mountain between 2007-2023 years.

A significant negative correlation was found between breeding density and brood size across years, though the degree of statistical significance was modest (r=-0.52, p=0.047) (Fig. 3).

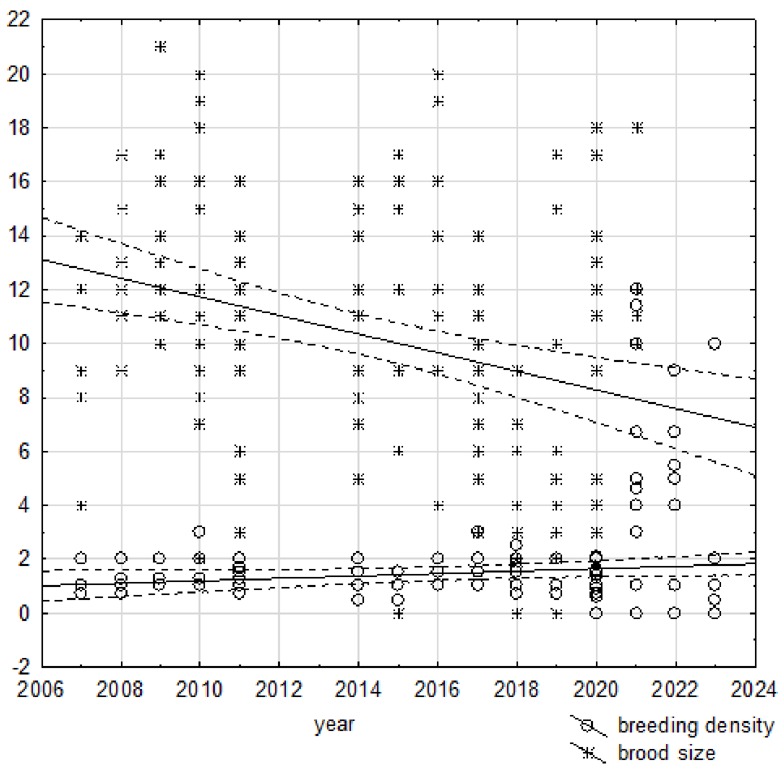

Fig. 3. Relationship between breeding density (pairs/100ha) and mean brood size (individuals) over the entire study period.

A loss during autumn-winter period varies from 2.3% to 15.8% and decreases from 2018 to 2023 years (Table 1).

Table 1. Autumn-winter and spring-summer losses of Grey Partridge in the Sakar Mountain region from 2018 to 2023.

year	losses (aut./wint.) %	losses (spr./sum.) %
2018	15.8	41.2
2019	13.8	50
2020	9.3	50.1
2021	4.48	76.3
2022	2.3	57.8
2023	5.88	33.8

The mean losses during the spring-summer period were 51.5%. A strong positive correlation was observed between breeding density and losses during this period ($r=0.845$, $p=0.03$) (Table 1). In contrast, no significant relationship was found between average brood size and the percentage of autumn-winter losses ($r=0.61$, $p>0.05$).

Discussion

The Grey Partridge population has been monitored in several European countries in recent decades, to support effective species management (Panek 2006, Ewald *et al.* 2009, Bro 2016). Long-term monitoring data indicate a continued decline in the species' population density (Birdlife International 2022, Keller *et al.* 2020). Some studies have also reported a downward trend in partridge reproductive success (Panek 2005, Grubešić *et al.* 2006, Godin & Reitz 2019, Godin *et al.* 2021). The breeding density observed in our study is significantly lower than that found in the Thracian Lowland (Angelov 2022) and in many European countries (Kugelshafter & Richarz 2001, Šálek *et al.* 2002, 2004, Bro *et al.* 2005, Rosin *et al.* 2010, Bro *et al.* 2014). However, various studies have reported densities ranging from a few pairs to over 50 pairs per square kilometer depending on the habitat (Bro *et al.* 2005). The density found in our study is closer to that reported for mountainous regions of some European countries (Šálek *et al.* 2002, 2004, Alexiou *et al.* 2005, Bro *et al.* 2005, Panek 2006, Purroy & Purroy 2016).

The dynamics of the population density over the study period show a relatively constant breeding density in the study area, likely due to the habitat reaching its capacity. This pattern is observable in the long duration of the present study, which is not typically seen in short-term studies. The breeding density in the study area is significantly lower than in other regions of Bulgaria. In the Thracian Lowland, breeding densities have been reported between 4.6 and 7.6 pairs /km^2, with these differences attributed to varying habitat productivity (Angelov 2022). The density reported for Sakar is lower than that found for the species in the 1990s in the Thracian Lowland, where densities ranged from 2 to 55 pairs /km^2 (Milanov 1991). In northern Bulgaria, densities between 1 and 14.4 pairs /km^2 were reported at the end of the 20th century (Botev 1962). These variations are likely due to differences in habitat productivity. Decreasing trends in Grey Partridge density in Bulgaria have been noted since the mid-20th century (after 1942), with further declines confirmed in the 1980s (Botev 1962). This decline likely continued into the 1990s, as indicated by studies early in the 21st century (Gerasimov & Mitev 2007).

In the Thracian Lowland, the Grey Partridge density remained stable between 2018-2020 years, with densities exceeding 16 pairs /km^2 in some hunting areas (Angelov 2022). These are one of the high breeding densities for the species reported in Europe. The monitoring results for common bird species in (Hristov *et al.* 2023) also indicate a stable to increasing density index for the Grey Partridge, a trend confirmed in the Sakar Mountain by the present study. The observed increase in breeding density is modest (Fig. 1), likely driven by a sharp rise in 2021. The subsequent return to densities similar to those in previous years in 2022 and 2023 suggest that the habitat has reached its capacity.

The average brood size across the entire study period was 10.26 fledglings per adult pair. This indicator remained stable, which aligns with findings reported by Botev (1962) for the northern part of the species' range in Bulgaria and is higher than that found in the Thracian Lowland between 2018-2020 years (Angelov 2022). The brood size in this study is also consistent with values reported from other parts of Europe (Rosin *et al.* 2010, Panek 2019). The negative relationship between breeding density and brood size, where increasing density results in smaller brood sizes (Fig. 3), was confirmed in this study. Similar trends were not observed in the Thracian Lowland (Angelov 2022), but have been reported in other parts of Europe (Rosin *et al.* 2010, Bro *et al.* 2015, Godin *et al.* 2021). This relationship is often observed in long-term studies and may not be evident in short-term studies. The decrease in brood size with increasing breeding density supports the hypothesis that the habitat has reached its carrying capacity. Some wild population management models combine demographic parameters with the impacts of hunting, agriculture, and other practices to estimate habitat productivity under specific conditions (Potts & Aebischer 1995, Godin *et al.* 2021). Such modeling should be considered when making future decisions regarding the sustainable management of the species in Bulgaria.

In this study, losses were categorized into spring-summer and autumn-winter periods. The average spring-summer loss in adult birds was 51.5%, similar to the 50.6% reported for the Thracian Lowland between 2018-2020 years (Angelov 2022). These losses align with those found in other parts of Europe, where losses during these seasons ranged from 50% to 51.7% (Serre *et al.* 1989, Millot *et al.* 2015). Recent studies have identified predation as a major cause of losses, but the present study does not provide evidence for specific causes. Nonetheless, spring-summer losses tended to increase with higher breeding densities, a relationship observed in previous studies (Potts 1980, Angelov 2022). It is also possible that spring losses are not purely due to mortality, but could be caused by emigration due to reaching habitat capacity, or by birds occupying unsuitable nesting sites during the breeding season (Panek 1997). Winter losses are frequently cited as a key factor affecting population density (Bro *et al.* 2000, Maletić *et al.* 2014). In this study, winter losses ranged from 2.3% to 15.8% in different years, among the lowest reported in Europe. Other studies report winter losses between 32% and 47% (Potts 1980, Watson *et al.* 2007, Godin *et al.* 2021). In the Thracian Lowland, winter losses were found to be 63.2% (Angelov 2022). Some studies identified correlations between habitat characteristics and winter losses (Brewin *et al.* 2020, Hille *et al.* 2021, Angelov 2022), but such relationships were not examined in this study.

Overall, the results indicate a slightly increasing trend in the Grey Partridge breeding density in the Sakar Mountains over the past 15 years. The species' density is lower compared to other areas of the country, likely due to differences in habitat quality. This study also found a negative correlation between breeding density and average brood size, and positive correlation between breeding density and spring-summer losses. Despite the low winter losses observed, no significant increase in breeding density was seen in subsequent years. This suggests that the habitat capacity has been reached, and the surviving birds may migrate to neighboring areas in the spring.

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