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Demographic Parameters of the Grey Partridge (Perdix perdix L., 1758) in Upper Thracian Plain (Bulgaria)

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Abstract. The Grey Partridge (*Perdix perdix*) is a common gamebird which population decreased dramatically across Europe, including Bulgaria as well. While recent studies report continuing declines in numbers, sufficient data on basic demographic parameters of the species in Bulgaria are scarce or lacking. Main objective of the present study is to provide up-to-date information on Grey Partridge demography in the arable lands of the Upper Thracian Plain (south Bulgaria). Breeding density was 6.27 ± 4.73 SD (min – max 0 - 20) pairs/km^2 and density in August averaged 57.32 ± 41.82 SD (min – max 0 – 148.06) individuals/km^2 during the monitored period (2018 - 2020). The Generalized Linear Model showed significant decrease of both breeding (Wald stat. = 65.47, $p < 0.0001$) and August (Wald stat. = 533.860, $p < 0.0001$) densities from west to east. However, direct reproduction parameters showed no geographic gradients and had relatively high mean levels as mean brood size was 9.0 ± 5.3 SD (min – max 1 - 26) young/successful pair (n = 163), chick survival rate up to six weeks of age was 0.56 ± 0.22 SD (min – max 0.19 – 0.94), brood production rate was 84.6 ± 20.9 SD (min – max 0 – 100%) and reproductive success was 3.96 ± 1.85 SD (min – max 0 - 8.5) young/adult bird. The present study shows highly unequal Grey Partridge breeding densities within the study area and suggests that diverse approach for management and restoration of the Grey Partridge will be needed across different parts of the Upper Thracian Plain.

Key words*:* breeding density, brood size, chick survival rate, brood production, spatial trend.

Introduction

In the lowland and hilly areas of Bulgaria, as well as through most of its European range, Grey Partridge (*Perdix perdix*) was a common gamebird with a high population density. However, since the middle of 20th century it is declining probably in all 31 countries within its range (McGowan & Kirwan, 2015). The most rapid decline in continental Europe occurred in the period 1960 - 1980 and continued in lower rate afterwards (Kuijper et al., 2009). Nowadays Grey Partridge is considered non-threatened species but with a decreasing population trend (Birdlife International, 2016). It is well documented that the dramatic decline is caused mainly by intensification of agriculture (Báldi & Faragó, 2007; Potts, 1986). Reduction of chick survival and suitable nesting cover and as a consequence increased predation are the factors believed to reduce Grey Partridge numbers by the late 20th century to less than 10% of those in 1950s (Aebischer &

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Kavanagh, 1997). Over the last two decades Grey Partridge densities remain under 5 pairs/km^2 over the most lowland territories in many European countries (Bro et al., 2005; Newson et al., 2005; Panek, 2006; Ronnenberg et al., 2016; Šálek et al., 2002) while breeding densities > 20 pairs/km^2 are scarce and derived from local habitat factors more likely established by chance (Bro et al., 2005; Šálek et al., 2004). Recently reported results from long-term studies show continuing decrease in some reproduction parameters of the species (Panek, 2019). Breeding density, reproductive success, brood production and chick survival rate are amongst the most important demographic parameters indicating the adverse effects of modern agriculture on Grey Partridge populations. Therefore, they have been studied across Europe either to estimate population status and determine the causes of decline (Bro et al., 2005; Panek, 2019; Potts & Aebischer, 1995) or to plan and assess effectiveness of applied habitat improvement measures (Buckley et al., 2021; Ewald et al., 2012).

Decline of Grey Partridge population has been observed in Bulgaria as well. In the middle of the 20th century the species was described as common in plains and low mountains of the country (Patev, 1950) and during the first half of the 1980s breeding population reached about 600 000 ind. (Simeonov et al., 1990). Decrease in Grey Partridge numbers took place afterwards and two independent studies reported estimates of 20000 – 30000 pairs in 2004 (Nankinov et al., 2004) and 10000 - 25000 pairs in 2007 (Gerasimov & Mitev, 2007). Detailed data on breeding density and reproductive parameters of the Grey Partridge in Bulgaria are currently missing apart from a study in Sakar Mountain in which low breeding densities (1.23 ± 0.19 pairs/km^2) and a reproductive success of 2.97 young/adult individual are reported (Gruychev & Angelov, 2019). In Bulgaria, the Grey Partridge is subject to hunting (Hunting and Game Preservation Act, 2000) and it is one of the most preferred gamebirds by Bulgarian hunters, especially in lowland hunting districts of the country. In attempt to maintain sustainable harvest of the species, each year the hunting clubs set hunting bag limits based on the estimated spring density, theoretical reproductive success, expected winter losses (after closing the season at the end of November) and the target density for the next spring.

Nowadays, the western parts of the Upper Thracian Plain are believed to sustain one of highest Grey Partridge densities in Bulgaria but over the last 30 years there are no published data on basic demographic parameters of the species in this part of the country. Over this period major changes in agricultural practices took place, especially after Bulgaria joined the EU in 2007, but their influence on the population dynamics of the species remains unclear. The aim of this paper is to present up-to-date information on Grey Partridge density and reproduction parameters of the population in the Upper Thracian Plain as a basis for current population status assessment and adequate research and management planning.

Materials and Methods

Study area

The study area is located in the Upper Thracian Plain (South Bulgaria) (Fig. 1) and covers a total of 4869 km^2. It is enclosed between the foothills of Sredna Gora Mountain to the north and the Rhodope Mountain to the south. The eastern limit of the study area is defined by Sazliyka River. The surveyed territory falls into Pazardzhik, Plovdiv, Stara Zagora and Haskovo provinces. The elevation varies between 130 and 350 m a.s.l. Woodlands occur sporadically and the landscape is comprised mostly of arable land dominated by cereal (mainly wheat and barley) and oilseed (sunflower being most common) crops.

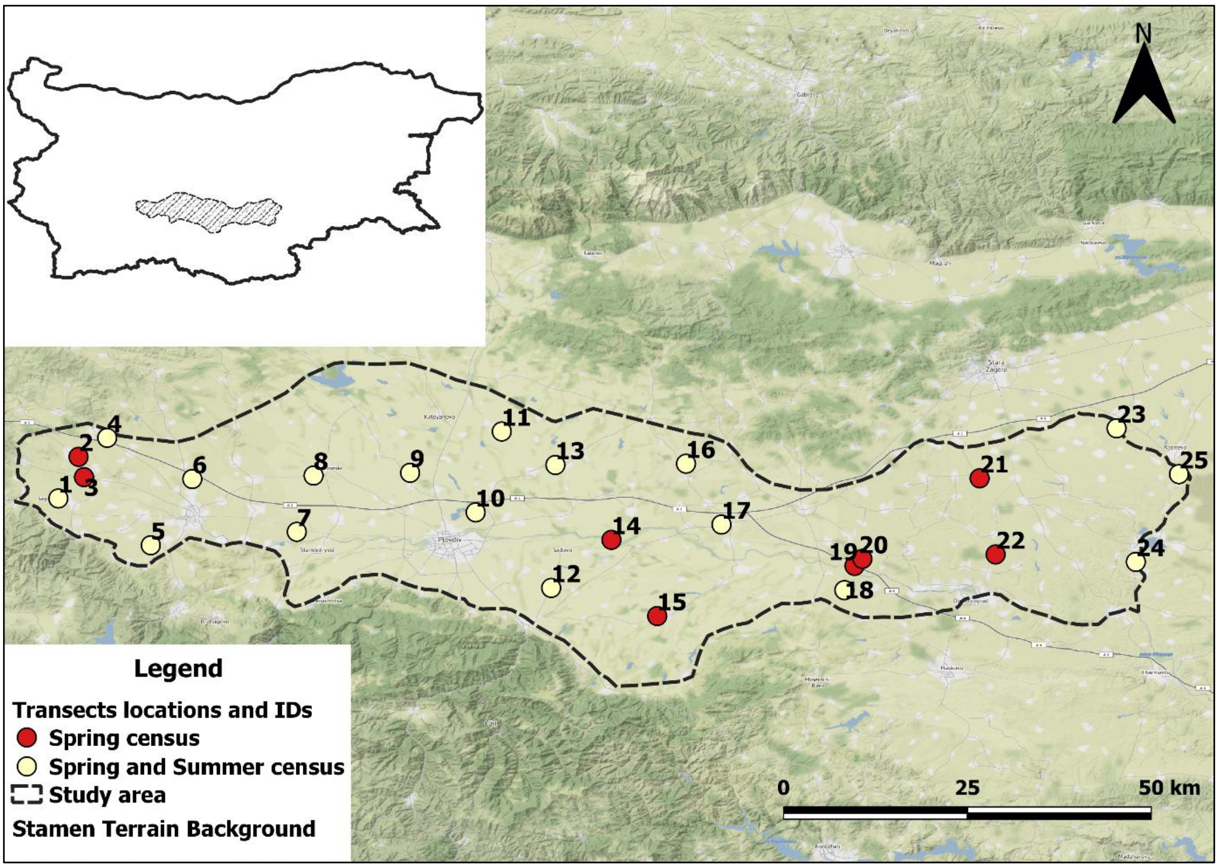

Fig. 1. Study area map. The transects are numbered according to their longitudinal distance from westernmost point of the study area. (Country borders on locator map are adapted from UNICEF (2019), under CC BY-IGO; Map tiles by Stamen Design (2021), under CC BY 3.0. Data by OpenStreetMap, under ODbL).

Breeding density

The breeding density of the Grey Partridge in the study area was estimated by a total of 25 line transects with average length of 5.13 ± 1.94 (min – max 2.10 – 8.89) km and width of 200 m (100 m on each side of the route). Playback calls were used alongside the transects in order to increase the detectability of Grey Partridges (Gruychev & Angelov, 2019; Rosin et al., 2010). The volume of the speaker was adjusted so that the sound was audible at about 100 m distance and the male partridge song was played every 200 m, thus covering the whole area of the transect. Each transect was visited at least twice from beginning of March to 10th of May between 2018 and 2020 in order to collect sufficient data. When playback is used during census even one visit on the transect could be enough as the vocal activity of male partridges remain relatively constant in March and April (Panek, 1998). The Grey Partridge density was determined by transforming the maximum number of counted pairs relative to 1 km^2 area (Bibby et al., 1992).

Summer census

Surveys during the period mid-July to mid-August were carried out on part of the transects used to estimate Grey Partridge density in the spring (Fig. 1). Fifteen sites were monitored between 2018-2020 and two transects (7 and 13) were visited in 2019 and 2020, thus a total of seventeen sites were censused in summer over the study period. The selection of transects to be surveyed in the summer and the number of visits on each of them were chosen in such a way that at least 30 – 40% of females counted in the spring had been observed in the summer (Bro et al., 2003). Trained hunting dog was used to flush the birds and thus increasing their detectability (Bibby et al., 1992). For every flock observed the number of young and adult birds were recorded. In order to assess the breeding success of the Grey Partridge during the monitored period four basic reproduction parameters were calculated. Brood production rate (BPR) was determined by the percent of pairs that have successfully reproduced, i.e. reared at least one chick during the survey. Brood size was calculated as arithmetic mean of number of young in each observed flock. Reproductive success was determined by the young-to-old ratio (including unsuccessful pairs) on surveyed sites (Rosin et al., 2010). The chick survival rate (CSR) up to six weeks of age was calculated according formulae proposed by Potts (1986), where CSR = 0.03665(geometric mean brood size)^{1,293} when geometric brood size < 10 and CSR = (geometric mean brood size)/13,84 when geometric brood size > 10.

The data collected during the summer censuses was used to estimate the August density of the Grey Partridge in the study area. The transect width was set on a total of 100 m (50 m on each side of the routes) as this was the mean distancing of the dog from the route. Given the census area and the number of recorded individuals, the August density was calculated as individuals/km^2. Obtained results on this demography parameter of the Grey Partridge were compared with the threshold of 20 birds/km^2 that should be maintained in order to conduct any shooting (Tapper, 2001). As losses between August and 1st October (start of hunting season) are possible and augmentation in abundance is very unlikely to happen, thus a minimum number of sites not capable of sustaining any harvest was derived.

Statistical analysis

In order to investigate geographical variation of estimated demographic parameters of the Grey Partridge a direct gradient analysis approach was adopted (Ter Braak & Prentice, 1988). As the distribution of the data was apart from the normal, a Generalized Linear Model (GLM) (Poisson distribution, Log link) was used. The aim of the analysis was not to predict the Grey Partridge density or values of the reproduction parameters at a given pair of geographical coordinates. As this would hardly be appropriate for a sedentary species inhabiting arable lands, the GLM was actually used to investigate the significance of spatial variation of the estimated demographic parameter within the study area. Using the points of mean coordinates of the transects, the longitudinal and latitudinal deviations of each study site (in km) from the westernmost and southernmost points, respectively, were calculated. The routes of the transects were recorded on each visit via Garmin Oregon 600 GPS and later mean coordinates (in Coordinate Reference System: WGS84/UTM zone 35N) were derived with QGIS 3.14 standard tools (QGIS.org, 2021). A separate model was constructed for the spring and August densities, as well as for every estimated reproduction parameter. Each demographic parameter was included in the particular model as response variable and longitudinal/latitudinal deviations as explanatory variables. Together with the geographical variable, the year of census was included in all models as categorical explanatory variable. At first, the effect of each covariate on the response variable of interest was tested using the Wald stat. (in test of all effects). For the significant predictors (at $p < 0.05$), the direction of relationship with the dependent variable was determined according to parameter estimates of the model (McCullagh & Nelder, 1989). All tests were performed with TIBCO Statistica 14.0.0.15 (TIBCO Software Inc., 2021).

Results

Breeding density

The mean breeding density of the Grey Partridge over the whole study period was 6.27 ± 4.73 SD (min - max 0 - 20) pairs/km^2. The test of all effects highlighted the year of census as an explanatory variable with significant effect (Wald stat. = 17.832, p = 0.0001) on the breeding density. According to parameter estimates (Table 1), the breeding density in 2018 (Appendix 1) was significantly lower than in the two successive years. Both, the longitudinal (Wald stat. = 65.466, p < 0.0001) and latitudinal (Wald stat. = 9.085, p = 0.0026) deviations, were determined by the test of all effects as significant predictors of the Grey Partridge breeding density within the study area. The breeding density decreased as the longitude increased (negative parameter estimate) and as the latitude decreased (positive parameter estimate), with the former showing higher significance (Table 1).

Reproduction parameters

The average values of Grey Partridge reproduction parameters in 2018, 2019 and 2020 are presented in Table 2. When performed for each of the estimated reproduction parameters of the Grey Partridge, the test of all effects showed statistically significant effect of years on brood size (Wald stat. = 12.3712, p = 0.0021) and BPR (Wald stat. = 12.064, p = 0.0024), but not on reproductive success (Wald stat. = 3.9036, p = 0.1421) and CSR (Wald ^{2} = 1.4512, p = 0.4840). According to parameter estimates, only the year 2018 (of all three categorical variables) had significant positive effect on the brood size (Parameter estimate = 0.2018, Wald stat. = 8.1532, p = 0.0043) and negative on the BPR (Parameter estimate = -0.0862, Wald stat. = 11.971, p = 0.0005). Hence, in 2018, the brood size was significantly higher and the BPR significantly lower than in the following years.

The model showed no statistically significant effect of the geographical location on the brood size (Long: Wald stat. = 1.0395, p = 0.308; Lat: Wald stat. = 1.7879, p = 0.1812), the BPR (Long: Wald stat. = 0.247, p = 0.6194; Lat: Wald stat. = 2.753, p = 0.0971), the reproductive success (Long: Wald stat. = 0.5321, p = 0.4657; Lat: Wald stat. = 2.2251, p = 0.1358) and the CSR (Long: Wald stat. = 0.0622, p = 0.8030; Lat: Wald stat. = 0.4320, p = 0.511) for the test of all effects.

August density

Mean August density of the Grey Partridge over the 3-year period was 57.32 ± 41.82 SD (min – max 0 – 148.06) individuals/km^2. It averaged 59.06 ± 59.01 SD (min – max 0 - 210.67), 60.53 ± 64.66 SD (min – max 0 - 250) and 44.40 ± 28.93 SD (min – max 0 - 89.56) individuals/km^2 in 2018, 2019 and 2020, respectively. According to the test of all effect, the categorical variables (the years of censuses) were significantly related to the August density (Wald stat. = 52.336, p < 0.0001). The parameter estimates of years 2018 and 2019 (Table 3) suggest significantly higher August densities of the Grey Partridge in these years compared to 2020. The test of all effects determined the longitude as the only geographical variable related significantly (Wald stat. = 533.860, p < 0.0001) to the density of the Grey Partridge in August, while the latitude had no significant effect (Wald stat. = 2.392, p = 0.1219) on this demographic indicator. Parameters estimates showed inverse relationship between longitude and the August density (Table 3).

At least five (IDs: 21 - 25, Appendix 2) of all surveyed sites are not expected to yield numbers over 20 individuals/km^2 which should sustain shooting. In sites 21 and 22 no birds were observed during spring census, so the species is considered to be absent from these areas.

Table 1. Parameter estimates of the effect of each predictor on breeding density (Poisson distribution, LOG link, the year 2020 was set as a reference categorical variable, bolded values denote significant effects).

Effect	Level of Effect	Estimate	Standard Error	Wald Stat.	Lower CL 95,0%	Upper CL 95,0%	p
Intercept		**1.8281**	**0.2430**	**56.590**	**1.3519**	**2.3045**	**0.0000**
Longitude		**-0.0094**	**0.0011**	**65.466**	**-0.0118**	**-0.0072**	**0.0000**
Latitude		**0.0174**	**0.0058**	**9.085**	**0.0061**	**0.0289**	**0.0026**
Year	**2018**	**-0.2851**	**0.0714**	**15.909**	**-0.4252**	**-0.1451**	**0.0001**
Year	2019	0.0758	0.0650	1.358	-0.0517	0.2034	0.2440
Scale		1.0000	0.0000		1.0000	1.0000	

Table 2. Grey Partridge reproduction parameters per year and mean values over the study period (2018 - 2020).

	2018	2019	2020	Mean
Mean brood size ± SD	12.2 ± 4.9	8.7 ± 4.7	7.8 ± 5.4	9.0 ± 5.3
Min – Max	1 – 21	1 – 22	1 - 26	1 – 26
Chick survival rate ± SD	0.80 ± 0.31	0.49 ± 0.20	0.42 ± 0.16	0.56 ± 0.22
Min – Max	0.22 – 1.15	0.22 – 0.84	0.15 – 0.83	0.15 – 1.15
Brood production rate ± SD	77.1 ± 29.4	87.5 ± 14.9	88.4 ± 15.9	84.6 ± 20.9
Min – Max	0 - 100	0 - 100	0 - 100	0 – 100
Reproductive success ± SD	4.83 ± 2.58	3.61 ± 1.39	3.55 ± 1.23	3.96 ± 1.85
Min – Max	0 – 8.5	1.15 – 5.8	2 – 5.75	0-8.5

Table 3. Parameter estimates of the effect of each predictor on August density (Poisson distribution, LOG link, the year 2020 was set as a reference categorical variable, bolded values denote significant effects).

Effect	Level of Effect	Estimate	Standard Error	Wald Stat.	Lower CL 95,0%	Upper CL 95,0%	p
Intercept		**4.9016**	**0.0963**	**2591.855**	**4.7129**	**5.0904**	**0.000**
Longitude		**-0.0126**	**0.0005**	**602.632**	**-0.0136**	**-0.0116**	**0.000**
Latitude		-0.0047	0.0024	3.722	-0.0094	0.0001	0.0536
Year	**2018**	**0.0875**	**0.0276**	**10.042**	**0.0334**	**0.1416**	**0.0015**
Year	**2019**	**0.1112**	**0.0266**	**17.514**	**0.0591**	**0.1633**	**0.0001**
Scale		1.0000	0.0000		1.0000	1.0000	

Discussion

Breeding density

The spring density in the studied part of the Upper Thracian Plain has increased between 2018 and 2020 but as Grey Partridge populations often tend to be highly fluctuating (Bro et al., 2005) longer monitoring period is needed in order to clearly determine trends of demographic parameters. Grey Partridge average breeding density is higher than recently reported in Sakar Mountain (Gruychev & Angelov, 2019) which is likely to be a result of different habitat quality provided by both regions. Precise comparison between breeding density in the study area and on the remaining territory of Bulgaria could hardly be reliable due to lack of sufficient data. However, the mean breeding density of the species estimated in the present study is higher than the commonly reported across Europe and North America (Carroll et al., 2021; Montagna & Meriggi, 1991; Newson et al., 2005; Ronnenberg et al., 2016) although far from levels observed in some areas in France and Czech Republic (Bro et al., 2005; Šálek et al., 2004). The current estimated densities in the Upper Thracian Plain are comparable to the levels observed in Poland (Panek, 2005) and over most of France (Bro et al., 2015). Found average density of the Grey Partridge in spring is above the expected level of 4 pairs/km^2 in modern farmlands where no particular measures for species' habitats improvement are carried out (Aebischer & Ewald, 2004). As the breeding density significantly decreases from west to east this statement is mostly true for the western half of the study area. Considering only these parts of the Upper Thracian Plain, estimated densities (Appendix 1) are comparable to those achieved after Grey Partridge habitat improvements in United Kingdom and Hungary (Ewald et al., 2020; Faragó et al., 2012). On the other hand, the sites in eastern half of the study area sustain density levels similar or lower than reported for areas with modern agriculture and no habitat enhancements (Ewald et al., 2020). However, most sites maintain breeding densities of more than 2 pairs/km^2 (Appendix 1), thus enabling restoration of Grey Partridge population levels without releases of farm birds (Buner et al., 2011). The releases of commercially reared birds produced under intensive methods are proven ineffective for conservation purposes (Rymešová et al., 2012), yet they are still widespread among hunting clubs in Bulgaria.

As emphasized by Bro et al. (2005) Grey Partridge density levels vary considerably across space due to local factors, thus obscuring trend detection. It can be hypothesized that the significant spatial trends observed in the present study may be a result of global factors either related or not to human activity. Further investigations are needed in order to determine the specific factors causing decrease of density levels towards the southern and eastern parts of the study area.

Reproduction parameters

Mean brood size of the Grey Partridge in the Upper Thracian Plain is lower than reported in Sakar Mountain (Gruychev & Angelov, 2019) but similar to pre-decline levels in Poland (Panek, 2019) and those observed in Italy (Rosin et al., 2010). Brood size decreased over the monitored period but, unlike reported in some papers (Bro et al., 2015), it did not cause decrease in breeding density. The BPR and reproductive success are higher than those in Sakar Mountain (Gruychev & Angelov, 2019). The average estimates of these parameters in the present study, as well as estimates of the CSR, are similar to those observed after applying special habitat management in some areas of United Kingdom and Ireland (Buckley et al., 2021; Draycott, 2012; Ewald et al., 2012), although the chick survival tend to be higher in continental Europe than in Britain, due to the different climatic characteristics of these regions (Potts, 1988). Observed reproductive success is higher than the one reported in 1980s in Poland (Panek, 2006).

August density

Mean August density of the Grey Partridge is higher than the one estimated in Hungary (Faragó et al., 2012) and such as the breeding density decreases towards eastern limit of the study area. Results of the present paper show that at least 24% of surveyed sites in summer will produce autumn densities lower than the minimum required, according to Tapper (2001), for conducting shooting. The same author emphasizes that Grey Partridge population with such density in the autumn, after 55% winter losses, is capable to sustain density of 4.5 pairs/km^2 in the next spring, on farmland where no species' habitat improvements are applied. However, in sites 16 and 17 (Appendix 1), mean spring densities fail to reach these expected levels, albeit the mean estimated August densities were higher than 20 individuals/km^2 (Appendix 2). This could be caused by multiple environmental or management factors but, more importantly, these results suggest setting even higher autumn density threshold for conducting Grey Partridge shooting in some parts of the Upper Thracian Plain.

Conclusions

Despite the fact that the reproduction parameters of the Grey Partridge show no spatial trends across the study area and sustain relatively high levels, both spring and August densities remained low in eastern parts over the monitored period. This could be a result of multiple factors such as high winter losses, overshooting or emigration due to the lack of suitable nesting habitats. In general, further research on factors determining high spatial variation is necessary as the results of the present study suggest that diverse management approach will be needed across different parts of the Upper Thracian Plain. It is likely that restoration and management of the populations trough habitat enhancement will be most appropriate.

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Appendix 1. Grey Partridge breeding densities on monitored sites.

Transect ID	Breeding density (pairs/km^2)			
	2018	2019	2020	Mean
1	7.76	13.44	17	12.73
2	4.87	7.67	12	8.18
3	11.27	8.97	8.2	9.48
4	8.64	16.86	9.6	11.70
5	4.71	7.06	7.4	6.39
6	8.69	12.77	11	10.82
7	3.61	11.11	13	9.24
8	8.49	8.57	13	10.02
9	4.16	6.56	6.4	5.71
10	7.98	8.37	13	9.78
11	8.07	10.04	12	10.04
12	2.8	5.42	9.5	5.91
13	8.22	14.69	20	14.30
14	1.65	4.1	4.3	3.35
15	0.91	1.01	5.1	2.34
16	2.96	0.77	3.5	2.41
17	2.75	5.72	4.4	4.29
18	10.97	7.65	3.1	7.24
19	0.83	1.02	3.2	1.68
20	0	3.3	4.8	2.70
21	0	0	0	0.00
22	0	0	0	0.00
23	2.62	2.99	5.3	3.64
24	0	1.49	0	0.50
25	3.44	5.98	3.4	4.27
Mean ± SD	4.62 ± 3.63	6.62 ± 4.77	7.57 ± 5.31	
Min - Max	0 – 11.27	0 – 16.86	0 – 20.00	

Appendix 2. Grey Partridge reproduction parameters on monitored sites.

Transect ID	Brood size	BPR	Reproductive success	CSR	August density
1	10.6	100.0	5.75	0.61	95.8
4	9.9	83.6	4.06	0.62	110.0
5	8.4	95.2	3.97	0.50	44.6
6	8.8	70.8	3.29	0.53	90.0
7	10.6	81.3	4.25	0.61	105.5
8	10.5	91.7	4.37	0.54	61.8
9	7.8	66.7	3.16	0.40	24.7
10	10.9	70.0	3.19	0.60	60.2
11	7.7	90.5	3.20	0.38	52.8
12	10.5	84.7	4.45	0.70	60.4
13	8.5	90.0	3.89	0.49	148.1
16	5.8	50.0	2.88	0.83	20.6
17	5.7	83.3	2.50	0.34	24.8
18	12.1	100.0	6.37	0.84	55.9
23	8.5	100.0	4.25	0.58	8.6
24	3.0	100.0	3.00	0.37	7.9
25					0.0