Does provision of supplementary food to grey partridges *Perdix perdix* help their over-winter survival on upland hill farms in northern England?

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SUMMARY

Grey partridge populations in the UK have declined dramatically since 1970. These birds are mainly associated with lowland cereal farms, but they are also found on marginal hill farms in northern England where they frequent rough grasslands created by low-intensity sheep farming. Here, important populations remain, but the availability of winter food, particularly in years with prolonged snow appears a major limiting factor. To investigate whether food shortages in winter limit grey partridge survival, we experimentally tested whether we could improve their survival by increasing the provision of supplementary food within five study plots, each paired with a control, over two consecutive winters. Grey partridges found and used feeding stations, with discovery time on average 12 days earlier in the second winter. The frequency of hopper use also increased on four of the five fed plots in the second winter. We found no differences in an index of over-winter survival nor subsequent breeding success in relation to the feeding treatment. However, the study coincided with two mild winters with little snow and the provision of supplementary food may be more important in more severe winters with prolonged snow cover. Grey partridges readily used feed hoppers and we recommend their provision to provide emergency food sources in severe winter weather whilst longer-term land-use based solutions are sought.

BACKGROUND

The grey partridge *Perdix perdix* is primarily associated with lowland cereal agriculture and was a common and widespread bird throughout Europe before the Second World War (Potts 1986). In the UK, grey partridge numbers fell by 92% between 1970 and 2015 (Hayhow *et al*. 2017) linked to the intensification of agriculture (Potts 1986) leading to it being red-listed as a Bird of Conservation Concern (Eaton *et al.* 2015). More efficient agriculture has resulted in a scarcity of natural farmland seed food during the winter (Robinson & Sutherland 2002, Potts 2012). The provision of cereal grain as supplementary food during the winter months is now recommended as an important component of wild partridge management in lowland cereal systems (Potts 2012, Sánchez-García *et al*. 2015, Aebischer *et al*. 2018). Grey partridges are also found on upland farms in northern England, where they frequent rough grasslands created by low-intensity sheep farming (Warren *et al*. 2017). Winter food, particularly in years with prolonged snow, can limit survival (Hawkins 1937, Ménoni *et al*. 2010). Supplementary feeding has been shown to be beneficial on an arable farm in France, where partridge density was higher in the area with additional feed than the area without (Westerskov 1977). Winter food may be important in determining population size on upland farms, where severe winter snow has been associated with high over-winter losses in black grouse *Lyrurus tetrix* occupying similar habitats (Warren *et al*. 2013). Here, although winter feeding of gamebirds occurs, it is targeted at pheasants *Phasianus colchicus* and feeders are often placed in woodlands, generally avoided by partridges (Westerkov 1977). To investigate whether food shortages in winter limited partridge survival, we experimentally increased the provision of supplementary food over two winters. We hypothesised that, (1) the provision of supplementary food may improve over-winter survival leading to increases in spring and summer densities, and (2) that continued feeding into spring would improve breeding productivity (chicks per pair and mean brood size).

ACTION

The study was conducted between 2010 and 2012 on 24 hill farms in Upper Teesdale (54º39’04.7’’N 2º08’20.9’’W) in the North Pennines Area of Outstanding Natural Beauty in north-east England (Figure 1). Ten study plots of average size 2.1 km^2 (range 1.7-2.6) (Figure 1) were selected in grey partridge habitats. These comprised rush pasture, meadow and rough grazing found on the edges of heather-dominated moorland (Warren et al. 2017). Plots were identified using grey partridge distribution from previous studies (Baines *et al*. 2007, Warren *et al*. 2018) and local gamekeeper observations. At the start of the study, grey partridges were at low density following high mortality during the previous severe winter (2009/10) with prolonged snow (Warren *et al*. 2013), thus study plots were selected to encompass remaining partridge populations in the Upper Teesdale study area. Grey partridges are sedentary (Šálek &

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Mahoul 2008) with spring dispersal recorded at an average 0.4 km in England (Potts 1986), although they can move a few kilometres, with an average 3.1 km recorded in Finland (Putalla & Hissa 1998) and in exceptional cases, up to 15 km, as found in introduced populations in North America (Church & Porter 1990), therefore study plots were located a minimum of 0.4 km apart. Grey partridges were already habitually feeding from 17 hoppers placed in the plots to encourage wild pheasants (Table 1). This resulted in only three of the ten plots having no feeders in place, with the other plots having between one and six feed hoppers present. Plots were paired in relation to their proximity to one another and the increased provision of food was then randomly assigned to one plot within each pair. Feeding was then provided at a rate of two hoppers (of similar design to existing hoppers) per known autumn partridge covey, with a minimum baseline of four hoppers per plot. Distances within plot-pairs averaged 0.7 km (se = 0.3, range 0.4-1.8) and that between-pairs was 0.9 km (se = 0.2, range 0.4-1.3). Between-plot movements of birds were quantified from 19 radio-tagged juveniles caught in autumn coveys in fed (n = 14) and control plots (n = 5).

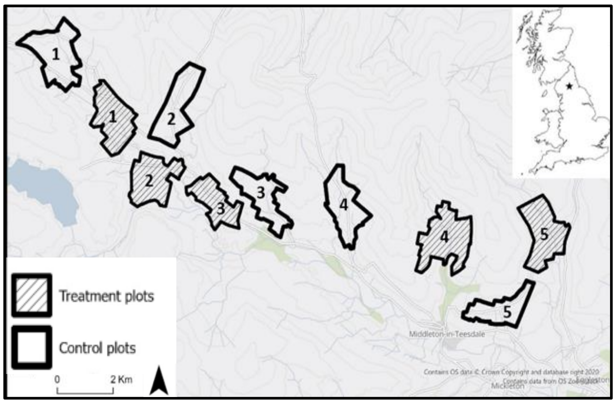

Figure 1. Map illustrating the location of the five treatment and control plots in Upper Teesdale County Durham, England (54º39'04.7''N 2º08'20.9''W).

In winter 2010/11, 57 hoppers were provided which, following an increase in autumn coveys in 2011, were increased to 76 in 2011/12 (Table 1). Feed hoppers consisted of a spiral feed dispenser attached to the bottom of a 25 litre capacity drum, suspended between two wooden posts (Figure 2). These were placed within a 1-m^2 fenced enclosure to prevent access by sheep and cattle. Hoppers were filled with wheat *Triticum aestivum* in November and checked weekly and refilled when necessary until late May. At each visit, we assessed partridge use of hoppers through bird sightings and searches for faeces. Meteorological data, specifically snow lying days $\geq$ 10 cm were obtained from the Hunt Hall Farm weather station in Upper Teesdale (54º40'06.5''N 2º13'46.0''W, 370m asl) located within 300 m of one of the study plots.

Figure 2. Feed hoppers were placed within fenced enclosures to prevent access by sheep and cattle

We surveyed partridges using a call-playback method (Warren *et al.* 2018) combined with point distance sampling (Buckland *et al.* 1993). Surveys were undertaken at dawn or dusk in spring (March, repeated in April) and again post-breeding (August, repeated in September) between summer 2010 and spring 2012. Surveys were conducted from a vehicle which stopped at ten vantage points at c. 400 m intervals along a 4 km route along minor roads and tracks all within each individual study plot. At each survey point, the observer played an audio recording of a male's call on a hand-held tape recorder held out of the vehicle window. This was played for 15 seconds, followed by a 15-second period during which the observer listened for calls of responding birds. Playing the call and listening was repeated four times at each sample point with a further two-minutes at the end spent listening and searching the area with binoculars. Positions of all birds seen or heard were plotted on 1:25,000 Ordnance Survey maps and the distance from the observer to the birds measured. We analysed distance data separately for each season and year using the program Distance 6.2 (Thomas *et al*. 2010). We used the conventional distance sampling analysis engine with a half-normal key function with cosine series expansion, and selected models which gave the best fit on minimum Akaike's Information Criterion scores and chi-squared goodness of fit tests. For analysis purposes we used the maximum count from the two visits in both spring and summer with density estimates generated for each plot.

To test whether hopper discovery time differed between plots and years we used a general linear model (GLM) with a normal distribution and identity link. The response variable, discovery time was calculated as the number of days from hoppers being erected to the midpoint between weekly visits when

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use by grey partridges was first recorded, with year and plot and the interaction as explanatory variables. The frequency of hopper use by partridges was tested using a GLM, with total number of observations (birds/and or faeces) per hopper per year as the response variable, with Poisson error, logarithmic link, ln(total number of weekly hopper visits) as offset, and plot and year and their interaction as explanatory variables. To test whether increased feeding improved over-winter survival, we used a GLM with a normal distribution and identity link. An index for over-winter survival was calculated as the ratio of change in densities between summer and spring (calculated by distance sampling using the program Distance 6.2), from: ln(spring partridge density in year t +1/ summer partridge (adults and juveniles) density in year t), for t = 2010, 2011, with treatment (increased feeding/control), year, plot pair and the treatment and year interaction included as fixed effects. Differences in two measures of breeding productivity, chicks per pair (dependent variable total numbers of chicks, offset ln(pairs)) and mean brood size (total number of chicks, offset ln(broods)); and spring and summer densities were considered separately within GLMs with the same fixed effects structure described above. Dispersal of radio-tagged juveniles caught in coveys (n = 19) and subsequently settling within plots or outside were considered using a 2 x 2 chi-square contingency table. All analyses were conducted using Genstat 17.0 (VSN International 2014).

CONSEQUENCES

Grey partridges used 96% of hoppers in the first winter and 100% in the second. The discovery time of hoppers differed between plots ($F_{4,91} = 5.95$, $p < 0.001$) and years ($F_{1,91} = 6.02$, $p = 0.016$). In the first winter,

Table 1. Numbers of feed hoppers present prior to, and during both winters in plots with no increased feeding provision (control: white) and with increased feeding provision (treatment: grey), hopper discovery and use, and the total numbers of grey partridges counted in each plot in autumn and in the subsequent spring.

Year 1 2010/2011

Plot pair	**No. feeders present prior to experiment**	**Total feed hoppers Year 1**	**Hopper use**		**Total partridges**	
			Days to discovery (se)	Frequency obs/visits (se)	Autumn [coveys]	Spring
1	0	0			0 [0]	0
	1	4	68.0 (12.0)	0.15 (0.09)	10 [1]	10
2	0	0			4 [1]	4
	1	7	59.0 (12.0)	0.22 (0.07)	14 [2]	16
3	2	2			28 (3)	3
	3	13	41.3 (4.0)	0.28 (0.04)	43 [4]	14
4	0	0			10 [2]	8
	6	22	24.3 (3.7)	0.57 (0.03)	79 [9]	26
5	2	2			12 [3]	16
	2	7	77.9 (8.9)	0.20 (0.07)	10 [1]	4
Total or average (se)	**17**	**57**	**43.1 (4.2)**	**0.37 (0.04)**	**210 [26]**	**101**

Year 2 2011/2012

Plot pair	**No. feeders present prior to experiment**	**Total feed hoppers Year 2**	**Hopper use**		**Total partridges**	
1	0	0			0 (0)	0
	1	8	58.1 (7.9)	0.43 (0.08)	9 (1)	14
2	0	0			24 (3)	6
	1	10	37.3 (8.8)	0.66 (0.07)	21 (4)	20
3	2	2			2 (1)	6
	3	15	29.5 (5.0)	0.69 (0.03)	59 (9)	24
4	0	0			58 (6)	16
	6	29	22.5 (2.5)	0.68 (0.03)	73 (11)	36
5	2	2			32 (6)	10
	2	10	28.1 (6.6)	0.64 (0.06)	35 (4)	18
Total or average (se)	17	**76**	**31.1 (2.7)**	**0.64 (0.02)**	**313 (45)**	**150**

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hopper discovery time varied between plots from an average 24 to 78 days and in the second winter from 22 to 58 days. Discovery time across all hoppers pooled was on average 12 days earlier in the second winter (Table 1). The frequency of hopper use showed a significant interaction between plot and year (X^2_4 = 29.62, p < 0.001) with high use in both years in feeding plot 4, while in the other four plots usage increased in the second winter from low levels in the first (Table 1).

An index for over-winter survival did not differ between feeding treatments or year with a non-significant interaction between treatment and year and averaged 62% (Table 2). No chicks were raised to fledging in either feeding treatment in 2012, with no significant differences in breeding productivity variables (chicks per hen and mean brood size) between treatments in the previous year (Table 2). Spring densities were significantly higher on the increased feeding plots ($F_{1,13}$ = 6.83, p = 0.021) in 2010/11 and densities increased significantly between years ($F_{1,13}$ = 11.49, p = 0.005) with a non-significant interaction between treatment and year. Spring densities increased by 137% on increased feeding plots and by 200% on controls. Similarly, summer densities were significantly higher on increased feeding plots ($F_{1,13}$ = 2.52, p = 0.014), and declined significantly between years ($F_{1,13}$ = 17.02, p = 0.027) with a non-significant interaction between treatment and year. Summer densities decreased by 55% on increased feeding plots and by 82% on controls.

There were no differences in the numbers of radio-tagged juveniles dispersing out or staying within feeding (four birds moved out, ten remained) or control plots (two birds moved out, three remained) (X^2_1 = 0.223, p = 0.637).

Costs

The costs associated with the project were the employment of a full-time research assistant (£22k per annum) who was responsible for the feeding programme and field data collection. The main capital costs were the provision of feed hoppers which were £20 each, with wheat kindly provided by the Raby estate.

DISCUSSION

We found no benefit of providing supplementary food to grey partridge over-winter survival, however the study took place over two mild winters with little snow. There were only 15 days with snow $\geq$ 10 cm recorded in the first winter and two in the following winter, making them the lowest annual snow day totals in the last 60 years (Met Office, 2019). In contrast, the previous winter (2009/10), with 39 consecutive days with snow $\geq$ 10 cm, was the snowiest since 1985 (Prior & Kendon 2011) and negatively impacted black grouse survival (Warren *et al*. 2013).

Table 2. Grey partridge over-winter survival, breeding productivity and spring and summer densities in relation to feeding treatment and the results from GLMs to assess differences in the response variables between the main effects, treatment, year and plot pair and the treatment and year interaction. A = treatment, B = control

	2010/11		**2011/12**					
	A mean ($\pm$ se)	**B mean ($\pm$ se)**	**A mean ($\pm$ se)**	**B mean ($\pm$ se)**	**A**	**Year**	**Plot pair**	**A *year**
Over-winter survival (n = 20)	0.59 (0.16)	0.70 (0.21)	0.70 (0.13)	0.47 (0.18)	NS	NS	NS	NS
Productivity (chicks / hen) (n = 10)	5.2 (0.8)	4.2 (1.7)	-	-	NS	-	NS	-
Productivity (mean brood size) (n = 10)	6.2 (0.5)	5.4 (2.0)	-	-	NS	-	NS	-
Spring densities (birds km^{-2}) (n = 20)	25.4 (6.3)	10.6 (3.8)	60.2 (18.7)	31.8 (9.6)	$F_{1,13}$ = 6.83 p = 0.021	$F_{1,13}$ = 11.49 p = 0.005	$F_{4,13}$ = 4.20 p = 0.021	NS
Summer densities (birds km^{-2}) (n = 20)	168.5 (44.0)	122.8 (41.6)	75.5 (26.5)	22.5 (14.3)	$F_{1,13}$ = 2.52 p = 0.014	$F_{1,13}$ = 17.02 p = 0.001	$F_{4,13}$ = 3.90 p = 0.027	NS

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Provision of supplementary food may be more important to gamebird survival in winters with prolonged snow (Townsend *et al*. 1999, McLaughlin *et al*. 2019) when natural food sources are inaccessible to foraging birds (Ménoni *et al*. 2010). Prolonged snow may also increase susceptibility to predation, particularly by raptors when provision of supplementary food may mitigate predation risk by reducing foraging and hence exposure time (Watson *et al*. 2007, Potts 2012).

Partridges found and used feeding stations, but discovery time reduced and frequency of use (in four plots) increased in the second winter. This may be due to partridges not initially recognising this new food source or that natural food availability was not limiting in a mild winter. In more severe winter weather partridges may find and use these food resources faster and more frequently. Hoppers may also attract dispersing birds to settle and subsequently breed. However, we found no differences in juveniles moving out of treatment and control plots from the sample of radio-tagged birds present, therefore net immigration and emigration appeared consistent across all plots. No differences in breeding productivity were observed and any possible benefit to female condition from feeding was insufficient to prevent total chick mortality in 2012, the wettest June since 1910 (www.metoffice.gov.uk). This lack of demographic response is consistent with food provisioning trials involving wild grey partridges in France (Mayot *et al*. 2009) and from other studies on pheasants in the UK (Hoodless *et al*. 1999) and black grouse in Finland (Marjakangas & Puhto 1999), yet spring feeding was found to benefit breeding success in released pheasants (Draycott *et al*. 2005).

In conclusion, grey partridges were attracted to supplementary food, but we detected no benefit to survival or reproductive success. Ideally, this study needs to be repeated during periods of more severe weather when natural food sources are covered by snow and ice.

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