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ORIGINAL ARTICLE

A spatial and temporal analysis of post-release behaviour in translocated Black Grouse (*Lyrurus tetrix*) using GPS telemetry

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Abstract
Limited post-release movements are crucial for the success of conservation programs involving translocation. While exploring their new habitat is imperative, excessive dispersals can undermine these efforts. In this study, we examined the short-term (60 days) and long-term (14 months) post-release movements of 43 Black Grouse (*Lyrurus tetrix*) that were translocated to the Hautes Fagnes (Belgium) in 2018–2019 and 2022 to evaluate their acclimation in the context of a population reinforcement. Our findings revealed significant individual variability in the extent of movements, yet mobile individuals exhibited a consistent trend: they engaged in exploratory movements for a period of 10–20 days after release. No discernible sex-related disparities in exploration distance were observed between years; however, the timeframe for reaching the farthest distance from the release point varied across years. After this exploratory period, the birds returned and settled in the target area (the moorland and peatland habitats of the Hautes Fagnes Nature Reserve), but this could be reinforced by the isolated situation of the target area, other moorland and peatland areas being beyond the observed range of our birds' explorations (maximum 22 km). The translocated Black Grouse settled in the central part of the reserve, despite a large available surface of moorlands and peatlands around, coinciding with the presence of other individuals and currently active leks in this sector. In both sexes, the exploratory period was followed by alternating periods of low mobility during summer and winter, and high mobility in autumn and spring. This mobility pattern aligns with typical behaviour observed in this species and is notably connected with periods of activity on leks in spring and autumn and a distinct restricted spatial behaviour during the winter. These findings suggest effective acclimation of the translocated grouse, contingent on other factors such as good survival rates and successful breeding.

Keywords Grouse conservation · GPS telemetry · Translocation · Post-release movements · Spatial behaviour

Zusammenfassung
Eine räumliche und zeitliche Analyse des Verhaltens umgesiedelter Birkhühner (*Lyrurus tetrix*) nach der Freilassung mithilfe von GPS-Telemetrie

Begrenzte Bewegungen nach der Freilassung sind entscheidend für den Erfolg von Artenschutzprogrammen, die Umsiedlungen beinhalten. Während die Erkundung des neuen Lebensraums unerlässlich ist, können übermäßige Wanderungen die Bemühungen der Programme untergraben. In dieser Studie untersuchten wir die kurzfristigen (60 Tage) und langfristigen (14 Monate) Bewegungen von 43 umgesiedelten Birkhühnern (*Lyrurus tetrix*), um ihre Eingewöhnung im Kontext einer Bestandserhöhung zu bewerten. Die Birkhühner waren in den Jahren 2018-2019 und 2022 in das Hohe Venn (Belgien)

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umgesiedelt worden. Unsere Ergebnisse zeigten eine erhebliche individuelle Variabilität in Bezug auf die Bewegungen, wobei mobile Individuen einen konsistenten Trend aufwiesen: Sie führten in einem Zeitraum von 10-20 Tagen nach der Freilassung Erkundungsbewegungen durch. Es wurden weder erkennbare geschlechtsspezifische Unterschiede in der Erkundungsdistanz festgestellt, noch zwischen den Jahren. Allerdings variierte der Zeitrahmen, innerhalb dessen die größte Entfernung vom Freilassungspunkt erreicht wurde zwischen den Jahren. Nach dieser Erkundungsphase kehrten die Vögel in das Zielgebiet zurück (die Moor- und Torfgebiete des Naturschutzgebiets Hohes Venn) und siedelten sich dort an. Dies könnte durch die isolierte Lage des Zielgebiets begünstigt worden sein, da sich andere Moor- und Torfgebiete außerhalb des von unseren Vögeln erkundeten Bereichs (maximal 22 km) befanden. Die umgesiedelten Birkhühner ließen sich im zentralen Teil des Schutzgebiets nieder, obwohl in der Umgebung eine große Fläche an Moor- und Torfgebieten zur Verfügung stand. Dies fiel mit der Anwesenheit anderer Individuen und aktiver Balzplätze in diesem Gebiet zusammen. Bei beiden Geschlechtern folgte auf die Erkundungsphase ein Wechsel zwischen Phasen geringer Mobilität im Sommer und Winter sowie hoher Mobilität im Herbst und Frühling. Dieses Mobilitätsmuster entspricht dem typischen Verhalten dieser Art und steht insbesondere im Zusammenhang mit der Aktivität an den Balzplätzen im Frühling und Herbst sowie deutlich eingeschränkten räumlichen Bewegungen im Winter. Diese Ergebnisse deuten auf eine erfolgreiche Eingewöhnung der umgesiedelten Birkhühner hin, die jedoch von anderen Faktoren wie guten Überlebensraten und einer erfolgreichen Fortpflanzung abhängt.

Introduction

Translocation serves as a conservation strategy aimed at reinforcing populations or reintroducing species to areas where they have become extinct or at bolstering dwindling populations (Soorae 2013; Destro et al. 2018). Although successful projects have been documented (Soorae 2013), the outcome of translocations is not always guaranteed. Individuals are released into an environment devoid of familiar landmarks, necessitating rapid acclimation for their survival (Frair et al. 2007; Berger-Tal and Saltz 2014; Clapp et al. 2014; Bell 2016). Factors such as predation, diseases, resource competition, human activities (e.g. disturbance, poisoning, poaching, traffic collisions) or long-distance dispersal movements can contribute to translocation failures (Le Gouar et al. 2012; Destro et al. 2018).

Considering that translocated animals are unfamiliar with their new environment, post-translocation exploratory movements are expected to occur frequently. To some extent, these movements may be necessary for acclimation, allowing the individuals to familiarize themselves with their new environment. This process can support a more efficient resource utilization and mate search. As their knowledge of the area increases, a transition from exploratory movements to knowledge-based movements within an established and familiar home range is expected (Berger-Tal et al. 2014; Picardi et al. 2022). These exploratory movements can pose challenges to the conservation process if individuals disperse too far or permanently depart from the release area (van Heezik et al. 2009; Kemink and Kesler 2013). Long-distance movements may be triggered by an instinct to rejoin the original population ('homing behaviour', e.g. Kesler et al. 2012), the unsuitability of the release area, rejection from local individuals, or mere disorientation and distress (Bain et al. 2012; Kemink and Kesler 2013; Ebenhoch et al. 2019). Such movements can elevate mortality risks due to increased predation exposure (Smetzer et al. 2021; Cohen et al. 2022) and high energy expenditure without a guarantee of resources (van Heezik et al. 2009; Le Gouar et al. 2012). Furthermore, individuals may permanently leave the target population that conservationists aim to restore. All of this could lead to undermine the restoration objectives (Le Gouar et al. 2012; Destro et al. 2018). The above underscores the significant impact of dispersal and exploratory movements on the success of reinforcements and reintroduction processes.

Over the past few decades, Black Grouse populations in Central and Western Europe have experienced significant declines, leaving the remaining populations generally threatened and isolated (Storch 2007; Ciach 2015). The root causes of this decline include habitat degradation, fragmentation and loss, compounded by climate change, predation and human disturbances (Loneux and Ruwet 1997; Loneux 2000; Ludwig et al. 2008, 2009; Storch 2013). In Belgium, the last remaining population resides within the Hautes Fagnes State Nature Reserve (Delcourt et al. 2018, 2022, 2023). This population began to decline in the 1990s after nearly three decades of relative stability during which the carrying capacity was 40–80 males (Ruwet et al. 1997; Loneux et al. 2003; Delcourt et al. 2023). From the early 2000s, major efforts had focused on habitat restoration, particularly peatlands, through several LIFE Nature projects. However, given the advanced stage of the Black Grouse population decline in the area, these endeavours alone proved insufficient. In 2016 and 2017, the population teetered on the brink of extinction respectively with only one and two males observed during courtship, prompting the urgent need for a safeguard program. It became imperative to swiftly bolster the population. Translocating individual grouse caught in the wild was selected as the best method, offering faster implementation and potentially superior outcomes compared to captive breeding (Mäkinen et al. 1997; Seiler et al. 2001; Liukkonen-Anttila 2001; Storch 2007).

Considering the above, we have established extensive monitoring of the post-translocation movements of Black Grouse (*Lyrurus tetrix*) that we translocated from Sweden to Belgium to preserve the remnant local population established on the Hautes Fagnes plateau.

This study aims not only to assess dispersal behaviours, which is one aspect of the likelihood of reinforcement success but also to gain comprehensive insights into Black Grouse behaviour following a translocation event. We first examined the short-term movements (60 days post-release) to: (1) measure their dispersal intensity, notably how far individuals move away from the target area (moorlands and peatlands in the Hautes Fagnes) upon release; (2) determine the duration of the exploration period; (3) assess their tendencies to settle into the target area. Next, we analysed the long-term movements (up to a year post-release) to determine whether birds change their activity over time, resuming a cycle classically known for this bird.

Material and methods

Capture, transport and release methods

The Black Grouse were captured in Kårböle (Ljusdal, Sweden), during late April of 2017–2019 and 2022. Translocations were not carried out in 2020–2021 due to Covid-19 safety measures. The birds were captured on leks situated on peatlands surrounded by boreal pine forests.

The Black Grouse were captured during courtship on leks using 'fall traps', triggered by the birds themselves. This period maximizes capture success as it concentrates males and females in a restricted area. Authorization for capture and translocation was granted by the Swedish Environmental Protection Agency (ref. NV-02318-17, NV-00524-18, NV-09269-21).

Transport to the Hautes Fagnes began within three hours after capture. The grouse were transported in 23 × 23 × 38 cm individual boxes with ventilation holes, lined inside with a substrate of mosses and lichens. Wild berries and apple slices were served as food. The journey, lasting approximately 24 h of non-stop driving, ensured release less than 30 h after capture.

To mitigate release-induced stress, the boxes were simultaneously opened in a shelter designed like a low tent, offering relative darkness and a single exit for the birds to go out at their own pace. During this process, the birds were not handled further and spontaneously left their transport box first, followed by the release tent. Releases occurred between April 25th and May 1st. None birds died during capture, transport, or release. In total, 88 Black Grouse (38 males and 50 females; Table 1) were translocated between 2017 and 2022.

Description of release sites

The release area is the 'Hautes Fagnes' plateau (Fig. 1) which encompasses the Hautes Fagnes State Nature Reserve (*ca.* 6000 ha; the largest moorland and peatland area in Belgium) and the surrounding spruce-dominated forests. Alongside lies the Elsenborn Military Camp (*ca.* 2,600 ha), with similar habitats. Both sectors are abundant in plants that constitute the dietary staples of the species, including ericaceous shrubs (*Erica tetralix*, *Calluna vulgaris*, *Vaccinium spp.)*, cotton-grass *Eriophorum spp.*, and birch *Betula pubescens* (Starling-Westerberg 2001; Wegge and Kastdalen 2008; Frankard 2016, 2021).

Since the 1990s, a significant area (1,450 ha) of surrounding forests, primarily spruce, has been logged and managed to restore the original peatlands (Frankard 2004; Plunus et al. 2013), particularly through recent LIFE projects (LIFE06 NAT/B/000091; Tourbières Hautes-Fagnes 2007–2012 and LIFE + 10 NAT/BE/706 Restauration des habitats naturels de l'Ardenne liégeoise 2012–2018). These LIFE projects also contributed to the restoration of 3460 ha of heathlands, peat bogs, and broad-leaved forests, of which 1960 ha underwent intensive interventions (such as sod cutting, milling, scraping, flooding, and deforestation), while 1500 ha were restored using less drastic measures (removal of isolated trees, maintenance work, etc.). Additionally, 178 kms of drainage ditches were systematically blocked. Post-LIFE actions have further restored 137 ha of moorlands and 350 ha of peatlands, with approximately 1000 ha deforested (work is ongoing).

The populated area of the core population (central part of the nature reserve—Delcourt et al. 2023) is considered as roughly stable for decades; although there was a phase of habitat closure, which was restored during the 2000s. The development of the moorgrass *Molinia caerulea* due to the drainage of humid heathlands and peat bogs for spruce cultivation had already become a significant issue by the

Table 1 Number of translocated Black Grouse (males and females) per year with the number of individuals with a GPS emitter indicated in parentheses

	2017	2018	2019	2022	Total
# Females	5 (4)	10 (8)	15 (7)	20 (9)	50 (28)
# Males	5 (2)	8 (8)	10 (6)	15 (7)	38 (23)
Total	10 (6)	18 (16)	25 (13)	35 (16)	88 (51)

No grouse were released in 2020 and 2021 due to Covid-19 travel restrictions. (For further details about the transmitters, refer to Supplementary Table 1)

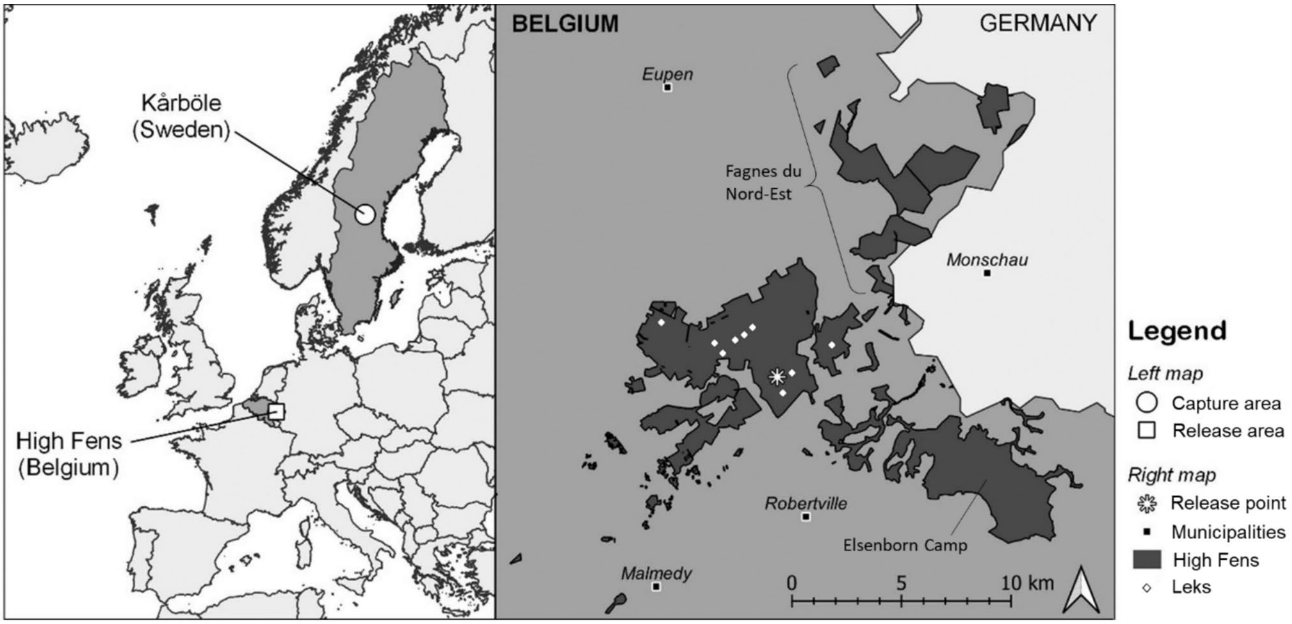

Fig. 1 Left map: Locations of capture and release sites depicted on a European scale. Right map: zoomed view on the release area in Belgium. The Hautes Fagnes (High Fens) and its surrounding moorlands and peatlands are represented in black. The white diamonds represented the active leks during the study period. Individuals are released in the most central sector. The North-Eastern sector is the Fagnes du Nord-Est and the South-Eastern sector is the Elsenborn Military Camp

1950s. A habitat utilisation analysis of the released Black Grouse is in preparation (unpubl. Data). A large majority of the habitat in the Fagnes de la Baraque Michel (i.e. Fagne wallonne, Fagne des Deux-Séries, Grande Fange and Fagne de Cléfaye), notably the restored areas, is frequently used by Black Grouse, particularly as resting, feeding, lekking, and breeding grounds. Degraded moor-grass heathland appears to be the least favourable heathland habitat for Black Grouse at first glance. However, these areas are regularly used by black grouse due to the presence of trees (birches, rowans, and spruces), which serve as perches, feeding sources, and even as display sites. All other open habitats with ericaceous vegetation are occupied by this bird, and open birch woodlands on peat soils are particularly favoured, especially in winter.

The release site is in the heart of the Fagne wallonne, within the Hautes Fagnes Nature Reserve, in an area with restricted access to the public. This site is abundant in Ericaceae and birch and is also close to active leks (see Fig. 1).

Marking

Each bird was fitted with a scientific ring from the Belgian Ringing Scheme on one leg, and a coloured ring engraved with a unique one-digit code on the other leg for identification from a distance.

To finely monitor their movements and survival, 28 females and 23 males (58% of the translocated Black Grouse) were equipped with a transmitter allowing GPS localisation. Different brands and models were deployed to find the most suitable transmission system while minimizing constraints on the birds. All transmitters were backpack-mounted and solar-powered.

In 2017 ($N = 6$), Ecotone GPS-UHF transmitters were used. Data retrieval relied on UHF connection via a hand-held device or an automatic receiver station. However, this system proved mostly ineffective, likely due to vegetation obstructing signal transmission, so data from 2017 were excluded from this analysis.

Subsequently, we transitioned to GPS-GSM technology, significantly enhancing data collection. In 2018, seven birds were equipped with an Ecotone GPS-UHF-GSM transmitter, and nine were fitted with an Ornitela GPS-GSM transmitter. In 2019 ($N = 13$) and 2022 ($N = 16$), Ornitela 13 g GPS-GSM transmitters were exclusively deployed. The transmitter weight relative to bird weight never exceeded 2.82%, staying within the globally agreed-upon limit of 3% (Phillips et al. 2003; Barron et al. 2010; see Supplementary Table 1 for details).

GPS localization intervals were managed via a web interface. Despite technological advancements, tracking Black Grouse with high-frequency data collection over extended periods remains challenging due to battery capacity depending on sunlight availability and transmitter weight (e.g. Kays et al. 2015). The number of localizations and data transmission frequency were adjusted based on battery level. Data collection varied from a few locations per day to several per hour. During winter, localization may be limited to one per hour or one per day under exceptionally poor light conditions; during other seasons, it ranged from one to five per hour. As the number of localizations varied overtime and between individuals, only the first location of every hour was retained for analysis to standardize data collection, so we used a maximum of one location per hour. We assume that one location per hour is here a good compromise between higher frequency during some periods and greater disparity during others, and too-low frequency does not accurately reflect movements. However, on winter days when data is recorded at less than one location per hour, we have also included data with a minimum of two locations per day to calculate distance and a minimum of three locations to calculate area.

Tracking data

On the 45 equipped individuals, two transmitters never transmitted, leaving available data from only 43 individuals. Nine transmitters stopped within the first 2 months, further limiting the dataset. Moreover, mortality rates were high in the first 2 months (about 60% in 2018–2019 and 30% in 2022). Nevertheless, we successfully tracked 18 individuals for two complete months and 8 individuals for more than a year. The number of individuals as a function of time and GPS fixes available for each individual is provided in Suppl. Figure 1 and Suppl. Table 2.

Spatial and temporal analysis

Post-release movements, based on GPS locations, were analysed on two different time scales: 60 days and 14 months following translocation. The 60-day period was chosen to encompass the highest predation risks and the end of the breeding period. Several grouse died before the completion of each study period. Depending on the analysis, these instances were either included or omitted from the dataset (specified in due course). Data manipulation was conducted using QGIS (v3.16.5-Hannover) and R (v4.0.5) (R Core Team 2024).

To assess how far the grouse dispersed from the release site, the maximal Euclidean distance from the release site was calculated, first accounting for 60 days post-translocation ($MaxDist_{60}$) and then extended to the whole study period ($MaxDist_{Tot}$). The number of days before reaching the furthest point was recorded. The time it took for a bird to reach this distance indicates its exploration period and dispersal intensity. $MaxDist_{60}$ and the time taken to reach it were compared between sexes using the Student's T test and between years using a one-way Anova.

To assess activity movement, the simple measure of distance travelled cannot be employed here due to non-constant localization frequencies over time and among individuals. To remedy this, daily home ranges during the first 60 days were calculated by the minimum convex polygon, encapsulating all the filtered daily locations (MCP 100%; Gula and Theuerkauf 2013). They were compared between years using a one-way Anova. This metric reflects the broadness of the area in which the grouse move daily, and how this area varies during the first 2 months. Contrary to the classic use of MCP, where the value of 100% is not recommended, here outliers must be included to account for significant displacements. All the data underwent rigorous validation to remove potential GPS localization errors. Additionally, the cumulative area of movement was investigated: each day, an MCP was delineated around the day's locations combined with all preceding locations (method illustrated in Supplementary Fig. 2). This method ensures that when an individual retraces its steps, it does not enlarge the area, which is useful for assessing the distancing process post-release.

After investigating daily movements, the extent of movement was measured weekly and monthly. Instead of using areas, in this case, movement extent was expressed as distance, calculated as the Euclidean distance between the two furthest points for each week or month (method illustrated in Supplementary Fig. 2).

Lastly, attention was paid towards the proportion of time spent within the suitable habitat area, referred to as the '*target area*'. Its boundaries were defined as the limits of the moorlands and peatlands areas, typical habitats known to be used by this species here, of the Hautes Fagnes, as well as the Elsenborn Military Camp, covering 7760 ha. These boundaries are presented in Fig. 1. The area outside the target zone consists of habitat that is not or only slightly attractive to black grouse: forests, pasturelands, agricultural fields, urban areas, and lakes. For each grouse, the proportion of GPS locations within and outside the target area was calculated for each month.

For the tests conducted, the normality of residuals and homoscedasticity were verified using distribution analysis, QQ plots, and the Shapiro–Wilk test. A logarithmic transformation was applied to the entire dataset to satisfy these conditions.

Results

Exploratory movements within the first 60 days

Maximal distance from release site

Upon release, the Black Grouse started moving and exploring their surroundings at varying levels. The most distant point reached within the first 60 days ($MaxDist_{60}$) averaged 6.84 ± SD 4.22 km from the release point (range = 1 to 22 km; $N = 43$) (Fig. 2, upper part). No significant differences were observed between males and females ($t = -0.1334$, $p = 0.89$), nor between years ($F = 0.0045$, $p = 0.95$). Excluding individuals tracked for less than 60 days, the average $MaxDist_{60}$ slightly rose to 7.01 ± SD 5.05 km ($N = 18$), with no significant difference between sexes ($t = 0.618$, $p = 0.55$) or years ($F = 0.3309$, $p = 0.57$).

For individuals tracked over 60 days, the time to reach $MaxDist_{60}$ ranged from 3 to 53 days ($N = 18$; all shown in Fig. 2, lower part). No significant differences were observed between males and females ($t = -0.71343$, $p = 0.49$); however, the rate differed between years ($F = 9.46$, $p = 0.007$). In 2018 and 2019, $MaxDist_{60}$ was reached after 25 days on average, compared to 8 days in 2022 (range = 3 to 21 days).

Daily amplitude of movement

Figure 3 shows the daily movement amplitude (daily MCP 100%). Individuals travelled over areas drastically larger during the first-month post-release (mean = 95 ha) than during the second month (mean = 11 ha). The highest mobility occurred in the two first weeks. During the first

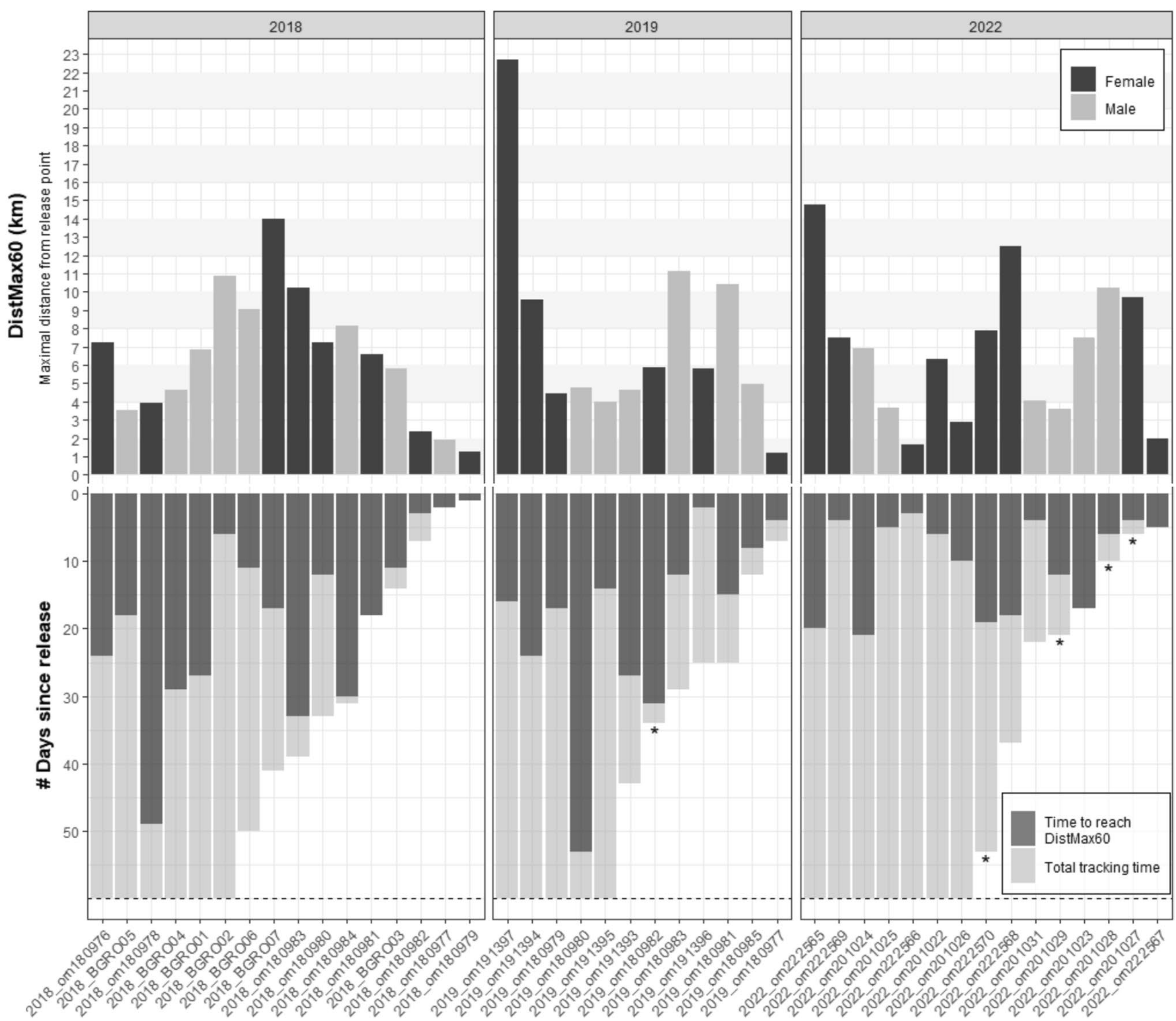

Fig. 2 Movement details of the tracked Black Grouse ($N = 43$), each individually is represented by a vertical bar. Individuals are grouped by year and sorted by descending tracking time within each year. *[Upper part]*: DistMax60, *i.e.,* most distant point reached from the release point within the first 60 days. *[Lower part]*: Dark grey, time elapsed before reaching *MaxDist60*. Light grey, total tracking time within the 60 days limit (18 Black Grouse tracked > 60 days). Asterisks are placed over individuals whose GPS connection was lost but without signs of mortality

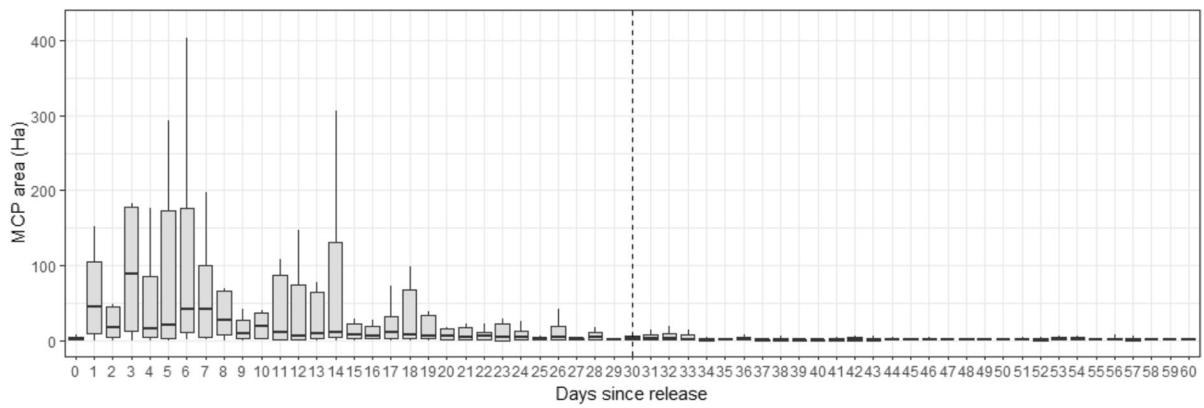

Fig. 3 Boxplots of the daily extent of movement during the first 60 days post-release, calculated as the area of the minimum complex polygon (MCP 100%) that could be drawn around all the positions of each day. Only individuals tracked > 60 days are included ($N=18$). Boxes represent the interquartile range (IQR 25–75%) and the median. The whiskers represent the minimum and maximum values respectively included in Q1 and Q3 ± 1.5*IQR (outliers were removed for readable purpose)

month, no significant differences were observed between years ($F=0.2555$, $p=0.78$). However, during the second month, 2018 was characterized by larger movements ($F=3.7357$, $p=0.039$; within average $dMCP_{2018}=49.6$ ha, $dMCP_{2019}=3.68$ ha and $dMCP_{2022}=6.55$ ha).

Cumulative area of movement

Figure 4 shows the cumulative area covered during the first 60 days, highlighting significant individual variation. The mean curve indicates the highest expansion rate was reached just after 1 week, with 50% of their 60-day visited area covered within that period. After this initial week, the expansion rate during these 2 months slowed progressively, showing a gradual decline in growth over time.

What did happen after 60 days?

Monthly extent of movement

The monthly extent of movement, measured as the distance separating the two locations furthest apart in a month,

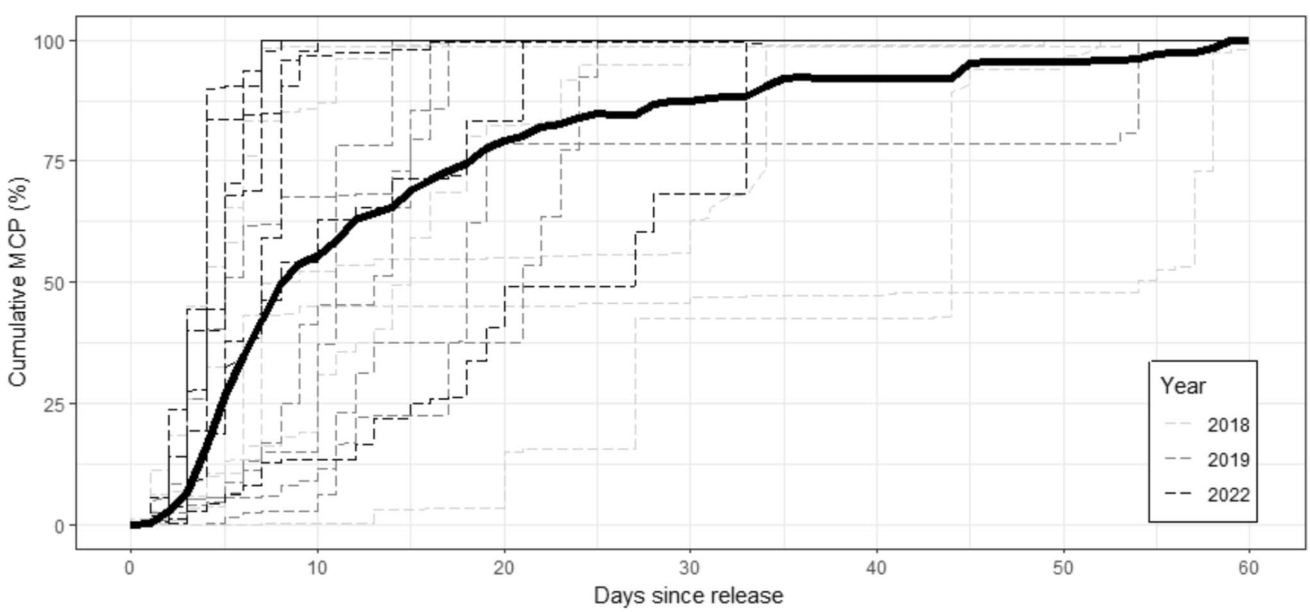

Fig. 4 Expansion of the area covered by the Black Grouse tracked > 60 days ($N=18$). Cumulative area is calculated for each day as the minimum convex polygon (MCP) including all positions since release and is expressed as the proportion of the total MCP at 60 days. Dashed lines represent each individual grouse, while the solid line represents the average curve

was investigated. Despite a limited number of individuals available for this long-term analysis, a pattern emerges (Fig. 5): the long distances travelled in the first month rapidly shortened, up to a point where all movements were concentrated in a very limited area. In July and August, almost all individuals (83%) moved over less than 2 km (av. $\text{Extent}_{\text{Jul.|Aug.}} = 1.3 \pm \text{SE } 0.2$ km). Then, there was an increasing mobility, characterized by longer displacements peaking in October ($\text{Extent}_{\text{Oct.}} = 5.8 \pm \text{SE } 1.0$ km), followed by a second decrease from December on (av. $\text{Extent}_{\text{Dec.|Jan.}} = 1.4 \pm \text{SE } 0.1$ km). In April, longer movements appeared again but with a high variability, even more marked in May: half of the individuals moved over 12 km or more, while the other half stayed below 2 km.

Weekly extent of movement

The extent of movement was analysed on a weekly basis and compared between males and females (Fig. 6, see also Suppl. Figure 3). Although displaying the same overall trend, differences were noticeable between sexes. The males' autumnal mobility peak lasted longer than the females'. If taking 1 km as a comparison threshold, males exceeded this value from week 17 to 32 (= 16 weeks), whereas females exceeded it only from week 20 to 27 (= 8 weeks). The males' autumnal peak also featured longer distances, averaging 3.2 km/week from September to November, compared to 1.8 km/week for females. These timing and distance differences during the autumnal peak seemed to reappear in the following year's mobility peak. However, with only two males tracked during that period, their behaviour may not represent the whole cohort.

Maximal distance from release site (> 60 days)

Out of 18 individuals followed for more than 60 days, 10 did not travel any further, 4 reached distances equivalent to their DistMax_{60} (difference < 3 km) and 4 travelled significantly further (Table 2). The longer movements rarely occurred during the autumnal peak, but rather during spring of the following year.

Proportion of time in/out of the target area

The individuals that survived the exploratory phase all ended up returning to the sector that was determined as suitable for the species, so-called the 'target area'. The proportion of time spent in and out of that target area (Fig. 7) shows that, upon release, both males and females spent considerable time outside of it. In late April and May, females spent on average 27% of their time outside, almost double that of males (15%). From June on, almost all individuals stayed within the target area more than 90% of the time, even during the autumnal peak of activity. As for the spring regain of activity, there was a higher variation, with some individuals mostly staying in the area and some others spending *ca.* 25% of their time elsewhere. After the exploratory period, the grouse almost never occupied the Elsenborn camp and the Fagnes du Nord-Est (eastern part of the nature reserve),

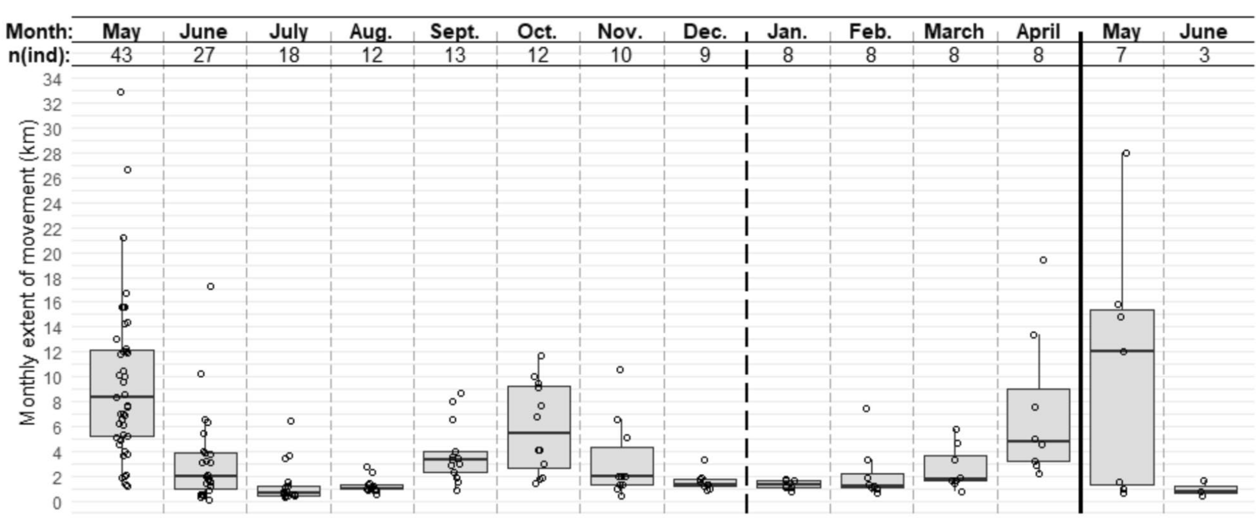

Fig. 5 Monthly extent of movement (both sexes), defined as the distance between the two points furthest apart in a month. The number of individuals (*n*(ind)) included in each boxplot is specified for each month, and the white dots represent the exact values for each individual. Boxes represent the interquartile range (IQR 25–75%) and the median. The whiskers represent the minimum and maximum values respectively included in Q1 and Q3 ± 1.5*IQR. The dashed vertical line represents the change of year, while the solid vertical line marks one year after the birds' release

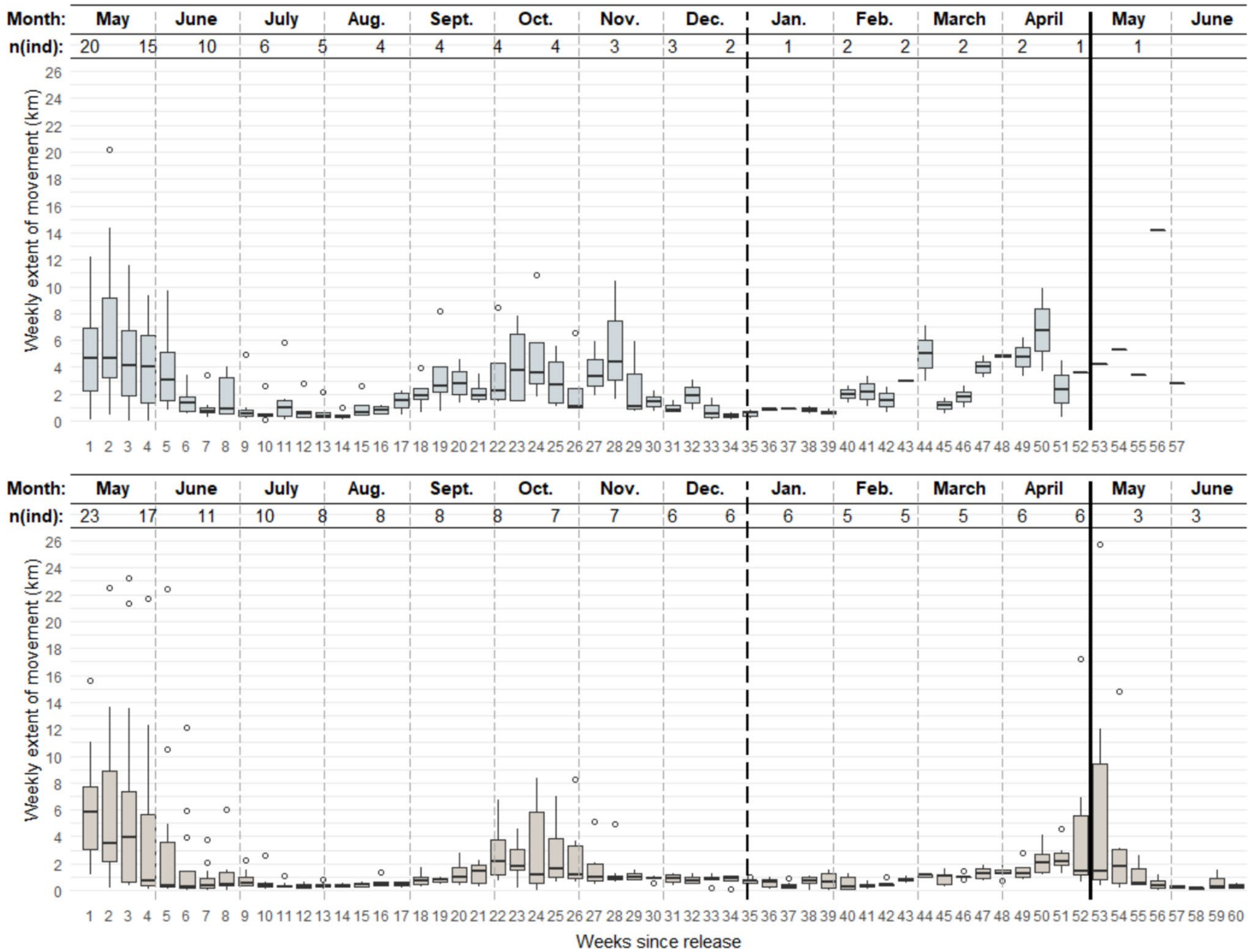

Fig. 6 Weekly extent of movement of males (top) and females (bottom), defined as the distance between the two points furthest apart in a week. The number of individuals (*n*(ind)) included in each boxplot is specified every 3 weeks, and the white dots represent the outliers. *n*(ind) is fluctuating in winter due to some transmitters failing to gather data during for some weeks, to preserve battery capacity. Boxes represent the interquartile range (IQR 25–75%) and the median. The whiskers represent the minimum and maximum values respectively included in Q1 and Q3 ± 1.5*IQR. The dashed vertical line represents the change of year, while the solid vertical line marks one year after the birds' release

Table 2 List of individuals that covered a greater DistMax *after* the first 60 days post-release

ID	Sex	Tracking	$DistMax_{60}$		$DistMax_{tot}$		Difference
2022_orn222565	F	426 days	14.8	(20th day)	26.1	(366th day)	**+11.3 km**
2019_orn180979	F	372 days	4.43	(17th day)	15.1	(372nd day)	**+10.7 km**
2018_BGRO05	M	351 days	3.55	(18th day)	10.0	(350th day)	**+6.45 km**
2022_orn201024	M	393 days	6.94	(21st day)	13.3	(388th day)	**+6.36 km**
2022_orn22259	F	374 days	7.52	(4th day)	9.87	(368th day)	**+2.35 km**
2018_BGRO04	M	128 days	4.63	(29th day)	6.15	(75th day)	**+1.52 km**
2018_orn180978	F	183 days	3.92	(49th day)	4.50	(152nd day)	**+0.58 km**
2022_orn201025	M	182 days	3.67	(5th day)	3.73	(167th day)	**+0.06 km**

$DistMax_{60}$ is the distance between release point and the furthest location within 60 days post-release. *$DistMax_{tot}$* accounts for the whole study period. DistMax expressed in kilometres. Between brackets: number of days elapsed before DistMax

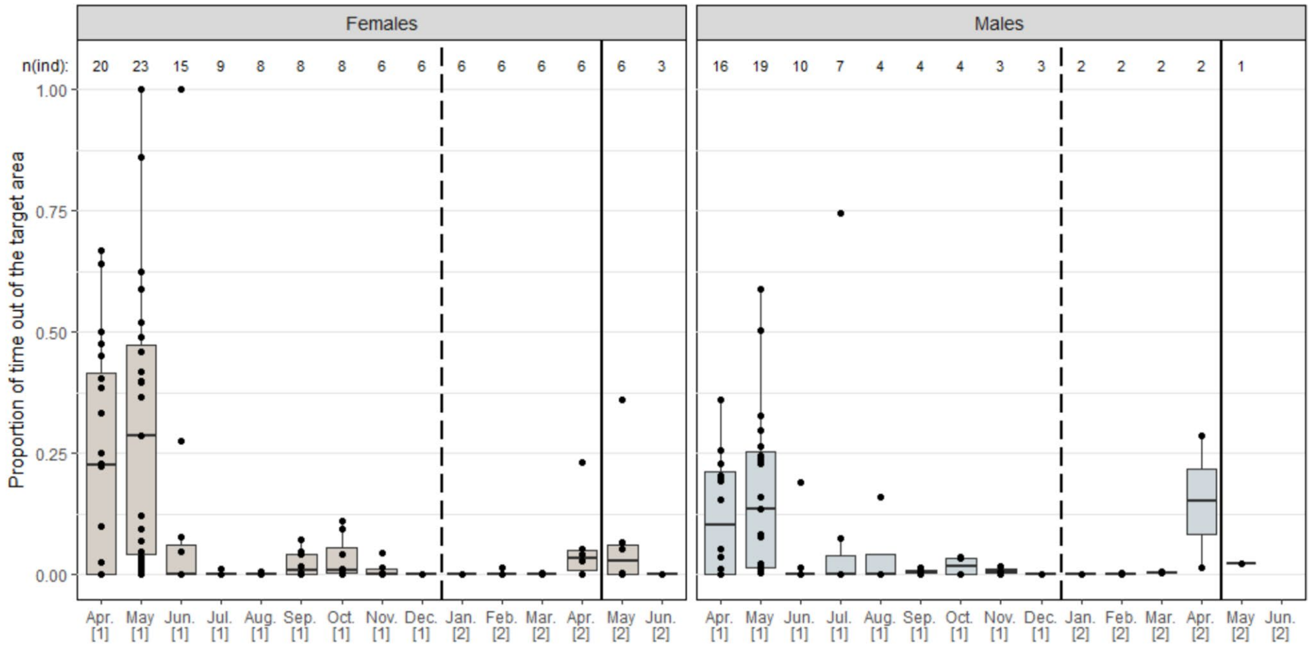

Fig. 7 Proportion of time spent outside the target area every month, from release date (late April) to June of the following year, for each sex. Each individual Black Grouse is represented by a black dot. The number of individuals (*n*(ind)) included in each boxplot is indicated for each month. Boxes represent the interquartile range (IQR 2–75%) and the median. Boxes represent the interquartile range (IQR 25–75%) and the median. The whiskers represent the minimum and maximum values respectively included in Q1 and Q3 ± 1.5*IQR. The dashed vertical line represents the change of year, while the solid vertical line marks 1 year after the birds' release

remaining essentially confined to the central part of the reserve.

Discussion

Recent translocation programs of Black Grouse have been undertaken in northern England (North Yorkshire) (Warren et al. 2017; Warren and Baines 2018), the Netherlands (Sallandse Heuvelrug; pers. comm. P. ten Den), Germany (Rhön Biosphere Reserve) (pers. comm. K. Torsten), Poland (Bory Dolnośląskie Forest; pers. comm. R. Anglart) and Belgium (Hautes Fagnes; see also Høyvik Hilde et al. 2024). The translocation carried out in England differs as it involved grouse caught at night in late autumn–winter, and released within three hours at more than 15 km (Warren et al. 2017; Warren and Baines 2018). The other European projects are all similar in their method and objective than ours: they aim to restore lowland populations with grouse caught in spring on leks and involve over 1000 km translocations (Høyvik Hilde et al. 2024) from boreal to temperate areas. The Hautes Fagnes is the most distant destination area from the capture site, located 1400 km away.

Note that there are also Black Grouse release programs based on captive breeding. However, this traditional breeding approach has shown certain limitations in grouse species, particularly due to very high mortality rates (Seiler et al. 2001; Storch 2007). Captive rearing conditions can result in birds that are completely naïve to life in the wild, leading to the loss of essential survival skills, such as actively foraging for wild food and maintaining vigilance against predators, which increases their risk of predation (Költringer et al. 1995; Sokos et al. 2008). Additionally, captive-bred birds often exhibit issues related to the adaptability of their digestive tract due to conventional poultry food. This can lead to a shortened digestive tract (Putaala and Hissa 1995; Mäkinen et al. 1997; Liukkonen-Anttila 2001) and a gut microbiome different from that adapted to their natural diet (Wienemann et al. 2011). These reasons highlight why translocating wild birds is the preferred approach.

Reinforcement and reintroduction efforts should follow IUCN guidelines to maximize success (Storch 2007; WPA and IUCN/SSC RSG 2009). One fundamental requirement of the guidelines is a scientific analysis of such projects, which is the case in the Hautes Fagnes. This study specifically focuses on post-release movements. Our study is the only to precisely track daily movements and activity levels of translocated Black Grouse, measuring the exploration phase, post-release behavioural modifications, and individual variations.

Initial phase of exploration

The results revealed a wide range of exploration distances among translocated Black Grouse. None of the tracked birds has permanently left the release area unless they were predated before the end of their exploratory phase (four cases during the first month). Within 60 days, while some individuals remained within a mere 2 km radius of the release site, others ventured as far as 14 or even 22 km away. No discernible year-related disparities in exploration distance were observed. However, the timeframe for reaching the farthest point varied across years. This discrepancy might be linked to meteorological conditions, as factors like rainfall and ambient temperature can influence dispersal distances and propensity (Hardouin et al. 2014).

Despite these variations, no grouse exhibited behaviour indicative of 'fleeing' from the release area, the longer movements were interpreted as exploratory. If movements away from the release site were driven by stress or homing behaviour (e.g. Fischer and Lindenmayer 2000; Kesler et al. 2012), we would anticipate straight or directional movements, initiated promptly after release, covering substantial distances (e.g. Miller and Ballard 1982; Dickens et al. 2009; Tsoar et al. 2011). Instead, the analysis of daily MCP's and cumulative area revealed a gradual expansion of the travelled space over the first month (particularly noticeable in 2018 and 2019).

To our knowledge, no other studies have specifically examined dispersal distances during the exploratory phase in black Grouse. In our study, we did not observe any significant difference between sexes in terms of exploratory-phase dispersal (1–22 km, average 6.84 km from the release site). However, the four longest dispersal events were recorded in females, while the most dispersive male moved 11.1 km. Warren et al. (2017, 2018, see also McEwen et al. 2009) reported that males displayed on leks located 0.6–27.1 km away (average 3.6 km) and that females nested 0.6–6.9 km (average 1.7 km) from their release site. It is worth noting that in Black Grouse, natal dispersal is generally greater in females than in males, occurring in two distinct peaks: autumn and spring (Caizergues and Ellison 2002). In the Alps, they recorded natal dispersal distances of 1–29 km (average 8 km) for females and 0.2–8.2 km (average 8 km) for males. Similarly, Warren and Baines (2002) found comparable natal dispersal distances in northern England, with an average of 9.3 km for females and 0.8 km for males. While all these figures highlight the dispersal capacity of the species, it is important to note that they refer to different processes: exploratory dispersal (the first months post-release), natal dispersal of juveniles born in the wild (up until the following spring), and the selection of lekking and nesting sites in spring after a late-autumn or early-winter translocation.

Post-release behavioural modifications

After the exploration phase, shifts in behaviour indicative of acclimation are expected, referred to as post-release behavioural modifications by Berger-Tal and Saltz (2014). Following the exploration phase, our findings demonstrate a notable decrease in mobility in July and August. These movements, while covering shorter distances, were predominantly confined within the target area, which aligns with the need for "release-site fidelity" (Berger-Tal and Saltz 2014). This suggests that the landscape within the target area provides the necessary elements for the Black Grouse' life cycle, at least during those 2 months, which coincide with the end of the breeding season and the onset of moult (Cramp 1980; Lebigre et al. 2013). During this period, individuals are expected to focus primarily on exploiting food resources and resting sites, such as ericaceous shrubs and underbrush, abundant in the Hautes Fagnes.

In October, some individuals started moving again over longer distances while others remained relatively stationary. Even as mobility increased, over 90% of the movements still occurred within the target area, highlighting the Black Grouse's preference for this area. An increase of activity and mobility in autumn is described as common in both sexes (Rintamäki et al. 1999; Gregersen and Gregersen 2014). Males start searching for lek locations for the upcoming breeding season, as it appears to increase copulation success (Kokko et al. 1999) and some females undergo a phase of natal dispersal (Caizergues and Ellison 2002; Warren and Baines 2002).

Winter was characterized by a second phase of very low mobility, consistent with the literature. Since the number of GPS fixes was lower during this period due to reduced battery performance caused by low sunlight, the measured distances may potentially be underestimated. However, this reduced mobility can be explained by biological factors. In cold and snowy winters, Black Grouse spend most of their time in snow burrows and are active only during limited time windows (Marjakangas 1992; Loneux 2000; Arlettaz et al. 2007; Bocca et al. 2014). The average number of snow-covered days at our field site is 76.3 (range 22–115 days) for the period from 1971 to 2017, according to open data from the Royal Meteorological Institute at the local meteorological station (Mont Rigi). When snow cover is less extensive, Black Grouse tend to rest in the open, selecting roost sites based on their inaccessibility to predators, food proximity and topography (Bocca et al. 2014), remaining relatively static in either scenario.

Finally, a year after translocation, in April–May, two distinct behaviours emerged: half of the six females still being tracked remained in the close vicinity of the release site, while the other half engaged in long-distance movements, comparable to the post-release patterns (up to 26 km), yet ultimately returning to target area thereafter. Such 'back and forth' movements have been previously documented during spring natal dispersal and breeding dispersal of female grouse (Small et al. 1993; Caizergues and Ellison 2002). In our study, we suggest that these movements are driven by the search for mates (Small et al. 1993; Martin et al. 2000; Kemink and Kesler 2013). The combination of low male density on the leks being still low in the Hautes Fagnes (see below), with the natural breeding dispersal behaviour of females, may induce a search for males displaying at a distance. However, these results need to be confirmed, considering the limited number of tracked individuals 1 year post-release.

Individual variation

Although we were able to detect trends, such as the bimodal pattern of mobility throughout the year, we noticed a high degree of individual variation in distances travelled and overall activity. It is possible to explain it by differences among sex and life cycles, but another part seems to remain unexplained. Numerous studies and reviews highlight the influence of personality on movement propensity, regardless of the underlying reasons (e.g. Dingemanse et al. 2003; Cote et al. 2010; Chapple et al. 2012; Sih et al. 2012; Bamber et al. 2020). While this study did not investigate behavioural traits per se, the results nonetheless show behavioural variation within the studied sample, which is a crucial component of a viable population (Réale et al. 2007; Berger-Tal and Saltz 2014; Farine et al. 2015; Webber and Vander Wal 2018).

The density effect

The effect of local population density is challenging to assess here. We have no precise estimate of the number of females due to their behaviour, cryptic plumage, and the rarity of collected feathers or faeces, which limits available genetic information. Spring counts of males are in contrast available. The minimum number of males observed during spring counts carried out from 2018 to 2022 in April ranged from 2 to 12 (5 in the three study years), with 2 years without release due to COVID-19. During the lekking period, the number of displaying males per lek ranged from 1 to 7 (pers. obs.). Males may appear at multiple lek sites within the same season or even day (pers. obs.), a phenomenon noted since the population fell below twenty males (Ruwet et al. 1997). Spontaneous displays on tree tops outside lek sites are also commonly observed and indicate low density (Hoglund and Stohr 1997; Nelli et al. 2016). By May, most individuals are those introduced through translocation. However, the first 2 months show high mortality rates (over 50%), mainly due to predation, with no difference between sexes (unpublished data). Linking low density to bird retention in the target area is difficult. Low density might cause birds to either search for others elsewhere or remain in place due to a lack of social stimuli or competition (Matthysen 2005; Jreidini et al. 2024; Penttinen et al. 2024). At the end of the exploratory phase, translocated birds settle in the central part of the target zone (unpubl. data), even though other areas offer suitable habitats. One possible explanation is the presence of other individuals and active leks in this sector, which could create a social attraction.

Conclusions

Evaluating the success of a population reinforcement program through translocation requires measuring mortality rates, reproductive success, and post-translocation exploratory movement patterns (Storch 2007; WPA and IUCN/SSC RSG 2009). Our current study focused on the latter without pre-empting the other indicators, which are the subject of ongoing analyses.

Our study demonstrates that none of the tagged Black Grouse translocated from Sweden to Belgium exhibited homing behaviour or permanently left the area. None were therefore 'lost' due to long-distance post-release dispersion, a very important point in the context of a conservation program. We observed an initial phase of exploratory movements, followed by an alternation of seasonal phases of low and high mobility in both sexes. However, the results 1 year after release need to be confirmed, as the number of individuals still tracked at this time was limited.

We conclude that exploration within and around the target area (7760 ha) does not lead to disorganized, stress-induced dispersal. Instead, it suggests that the target habitat is suitable for the species. However, areas outside the target zone are primarily composed of forests, and at lower altitudes, pastures, lakes, and some urbanized zones, which may have also influenced the birds to return to the target area. Other peatland and heathland habitats exist elsewhere in this part of Belgium, but they are highly fragmented and, with very few exceptions, are located beyond the observed range of our birds' explorations (maximum 22 km). The closest noteworthy heathland and peat bog areas are approximately 1200 ha in the Hoge Kempen National Park, located 55 km away (nationaalparkhogekempen.be), and 682 ha on the Plateau des Tailles, 35 km away (biodiversite.wallonie.be). Additionally, a social effect could explain why the birds return and settle in the central sector, where other individuals are present and active leks are currently maintained. This likely illustrates an important advantage of reinforcement compared to reintroduction, as the remaining population could attract new arrivals to the target area, facilitating their establishment, even when very few individuals are initially present, with the latter potentially occupying certain sites of interest in the target area due to social traditions.

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Data availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval All applicable institutional and/or national guidelines for the care and use of animals were followed.

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