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Movements by edible dormice (*Glis glis*) to their hibernation site and implications for population control

Roger C. TROUT[1]*, Sarah BROOKS[2], Jasmine LIM[3], Danielle ROZYCKA[4], Peter GRIMSEY[5], Margaret GRIMSEY[5] and Lorna GRIFFITHS[6]

[1] *Holtside, Batts Corner, Dockenfield, Farnham, Surrey GU10 4EX, U.K.; e-mail: edibledormouse@hotmail.co.uk*
[2] *19 Teal Close, Walkington, East Yorkshire HU17 8TW, U.K.*
[3] *13 Orchard Court, The Orchard, Sallins Road, Naas, Co. Kildare W91 X5T1, Republic of Ireland*
[4] *69c Netherhampton Road, Salisbury, SP2 8NA, U.K.*
[5] *Arula, Bowstridge Lane, Chalfont St Giles, Bucks, HP8 4RD, U.K.*
[6] *4 Henley Close, Netherfield, Nottingham NG4 2PN, U.K.*

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Abstract. A feral population of edible dormice (*Glis glis*) has been monitored by examining a network of 230 nest boxes placed ca. 25 m apart within a 100 ha wood in southern England. Individuals have been microchipped as juveniles or adults to subsequently determine various parameters during their lifetime. Evidence from microchipping records indicated that most individuals were recorded in summer in one or very few adjacent nest boxes during their known lifespan – even for individuals recorded over ten years old. During most years between 2009 to 2016 radio collars were fitted in the autumn to a small sample of microchipped adult individuals. These adults were located periodically if possible using radio telemetry to determine the exact location of their winter hibernaculum. The distances and direction from the known nest boxes used were very variable. Some individual hibernacula were also successfully excavated to provide further information. The data are analysed and discussed in the context of preparing control operations where *Glis* are a pest in houses or woods.

Key words: nest box, radio tracking, hibernaculum, excavation

Introduction

The edible dormouse (*Glis glis* L. Gliridae, Rodentia), hereafter called *Glis*, is an alien pest species in Britain introduced in 1902 (Morris 2008). There is only one known meta-population of this species in the U.K., located across the Chilterns area west of London (Morris 1998, Trout & Mogg 2017). *Glis* is a long-lived arboreal mammal generally associated with deciduous forest with dense understorey, high trees and a well-connected canopy (Milazzo et al. 2003). Their reproduction correlates with years of good tree flowering of species such as beech (Burgess et al. 2003, Pilastro et al. 2003, Overgaard et al. 2007, Lebl et al. 2010), which leads to some years with a high level of breeding and some years with none at all and very few with moderate levels of breeding. From 230 nest boxes in ca. 35 ha on our study site the volunteer teams marked 1167 juveniles in 2011 but in 2012 no young were recorded.

They live above ground during the active season, generally lasting five months from late spring to mid autumn (Gaisler et al. 1977) and go into hibernation around late October in the U.K. for approximately seven months (Morris 1998, Morris & Morris 2010). In England, it is known that *Glis* use underground chambers as hibernation sites, utilising features such as rotten tree stump roots and old rabbit warrens (Thompson 1953, Brooks et al. 2012) whereas in parts of mainland Europe hibernating in caves may be common (Kryštufek & Flajšman 2007, Kryštufek 2010).

Glis are long lived in comparison to other small rodent species and have been recorded living nine years in Italy (Pilastro et al. 2003) and more than 10 years in the wild in the U.K. (Morris & Morris 2010). One male *Glis* was born in 2000 and was alive in 2014 and two litter-mate females born in 2000 both bred in 2013 (Trout et al. 2015). *Glis* thus have a life strategy

* *Corresponding Author*

of increased longevity and low rates of reproduction (including none in some years) coupled with long periods in hibernation. Typically, hibernation in mammal species is restricted to periods of cold or dry weather (Buck & Barnes 1999). Bieber & Ruf (2009) have shown that in outdoor enclosures, with *ad lib* food, dormice in non-reproductive condition may return to torpor/hibernation during the summer after very short active periods. They suggested this was a method of predator avoidance if tree-based (seed) food is scarce.

In Britain, *Glis* can reach high densities causing unacceptable nuisance and damage in houses and to forest trees (Jackson 1994, Morris 2008, Trout & Mogg 2017). Unlike other European countries, *Glis* are not legally protected in the U.K. but only certain control methods are approved under Licence. Poisoning *Glis* is illegal and a Licence is required to trap them (and they must be killed) or a different Licence to catch and release them. Control strategies in houses using live or killing traps aim to clear the infestations but are both expensive and largely ineffective (Trout & Mogg 2017), requiring frequent repetition in a given year, as well as annually. *Glis* control in U.K. forests has been considered (especially for newly emerging, isolated populations) but, as yet, is not widely implemented or monitored (S. Carter, pers. comm.). In Spain, France, Italy, Slovenia, Croatia and Russia, *Glis* were traditionally hunted for food, fur and medical utilization (Carpaneto & Cristaldi 1995, Ivashkina 2006) using both tree-based and cave entrance traps. The objective of that activity is to crop, not to control the population level (Kryštufek & Flajšman 2007).

A study site in the Chilterns was originally set up by Pat Morris in 1995. It contains beech (*Fagus sylvaticus*) as the dominant species (48 %) but also includes mature oak (*Quercus robur*) and other broadleaved species (20 %), and conifers (ca. 30 %). The study covers only part of the Hockeridge wood; 145 nest boxes have been checked once per month during each active season, continuing in 2017. The number of boxes was increased to 230 in 2008 to cover a larger proportion of the wood (ca. 25 %) and monitoring of all boxes increased to twice per month (Trout & Brooks 2012). The wood is ca. 100 ha and isolated on all sides by farmland with the exception of several hedges and a dual carriageway road to the north. The *Glis* population has been present in the study site for at least 50 years, and in very large numbers in recent breeding years (at least 536 individual adults and 1167 young in 2011).

A sample of 220 individuals of 5+ years old was selected and their presence in nest boxes during non-breeding years and the following breeding years were collated (Brooks et al. 2012). The percentage of the sample animals recorded in nest boxes out of those "known-to-be-alive" was significantly ($p < 0.001$) higher in breeding years (ca. 90 %) in comparison to non-breeding years (ca. 10-35 %). Both males and females displayed this behaviour. Those that were found in non-breeding years were mainly seen in the early summer. For example, none of 19 individual old *Glis* captured in 2012 (of a minimum total 151 known to be alive) were found after the first week in August. However, it is unknown where these "missing" animals refuge during non-breeding years or what they are doing. Most subsequently re-appear in the trapping history. This has potential implications for administrators planning any short term pest control strategy (i.e. over a single year).

Glis tend to be found in the same or adjacent nest boxes whatever their age and their nest box derived home range is apparently very small, often under 1 ha (Brooks et al. 2012). This is similar to ranges found from nest box returns by Seviana & David (2012) and radio tracking by Jurczyszyn (2006). However, it is much smaller than those determined from radio tracking data in Białowieża Forest in north-eastern Poland (Ściński & Borowski 2008) where average home range size (measured by 100 % minimum convex polygons) varied from 3.6 to 7.0 ha in males, which is significantly larger than for females who ranged from 0.55 to 0.76 ha. There is little to indicate where *Glis* hibernate relative to their summer range. Kryštufek & Flajšman (2007) and Kryštufek (2010) report that many Slovenian *Glis* can be seen travelling to individual cave entrances in the autumn, even creating a permanent furrow in the ground vegetation, but provide no data on the distances involved.

In this U.K. study we tracked animals which were radio collared in autumn to determine where individuals hibernated relative to their normal nest box location. We also sought to determine whether the apparent distances and direction involved were significantly different by gender.

Some *Glis* hibernacula were excavated to examine evidence for communality during hibernation. Information regarding *Glis* in excavated hibernacula from this study (and others such as Morris & Hoodless 1992 and Jurczyszyn 2007) is discussed as part of potential strategic approaches to consider when preparing for future population management of *Glis* where they are causing damage.

Material and Methods

Permanent marking using PIT tags has been used to identify individual *Glis* at this study site since 1996. The present study involves *Glis* between autumn 2009 and winter 2017. During the twice-monthly nest box checks, information including individual identification, weight, gender and reproductive condition were recorded. Marked *Glis* are only occasionally found in the nest boxes, not monthly throughout their life. During the autumn of most years from 2009 to 2016 a few individuals were fitted with radio collars weighing ca. 6 g. (Biotrack Ltd., U.K.), which incorporated a wire aerial within a heat-shrink tube surrounding a cable tie collar. The number of collars used varied according to financial circumstances. There was no attempt to collar animals in the two non-breeding years 2012 and 2015 when few animals were found in the autumn. The radio transmitters also differed from the "normal" specification, being short-lived but high-powered beacons adjusted to long-lived and low-powered beacons. Typically the pulse rate for the former was 30 per minute and the pulse length 25-30 msec, giving a life expectancy of about four months; the latter 20 pulses per minute and 20 msec duration. The collars were carefully fitted to the animals around the neck so that they were loose enough to be comfortable, but tight enough to stay in place and prevent forelegs from getting caught within. Once fitted with a collar, each animal was immediately returned to its original nest box and the signal frequency logged on a Biotrack receiver. Each radio collar was then tracked (using a three element Yagi aerial and Biotrack receiver) during the following few months to locate the position of the hibernaculum to within a metre. Limited resources prevented any attempt to work at night or to establish home range sizes.

Using the previous capture information from historical nest box checks, the main nest boxes used by each individual was allocated as the location refuge during the active season. Data relating to the distance to the hibernaculum were collated and analysed using the Rayleigh test (Fisher 1993) on log-transformed distances.

Male and female data were separated and the direction of movement from the refuge location during the active season to the hibernaculum was recorded as degrees from true North and collated in eight sectors representing 45 degrees; e.g. north ± 22.5, 45 degrees ± 22.5 etc. Differences in gender and asymmetry in direction were also tested using a circular regression model and Rayleigh test.

Some of the hibernacula were chosen to be carefully excavated to open the chambers and count the number of individual *Glis* present. No entrance/exit tunnel entrance could be felt, so each chamber was very carefully re-closed whilst leaving a tube (filled with leaves) to the surface to aid subsequent exit by the animals the following spring.

Table 1. Numbers of *Glis* radio-collared and hibernacula subsequently located.

Overwinter	*Glis* Radio-collared	Hibernacula found	Breeding year?
2009/10	18	12	Y
2010/11	18	12	Y
2011/12	Zero[1]		Y
2012/13	Zero		N
2013/14	20 + 2*	13 + 2*	Y
2014/15	13	9	Y
2015/16	Zero		N
2016/17	18	12	Y
2017/18	6**	5**	N
Total	93	65	

[1]no funds for collars in 2011. *Two animals in a nest box with earth covered paws radio-collared in spring returned to the natal nest box. **Collars from autumn 2016 replaced in early spring 2017 by 15 month duration collars to investigate double winter hibernation.

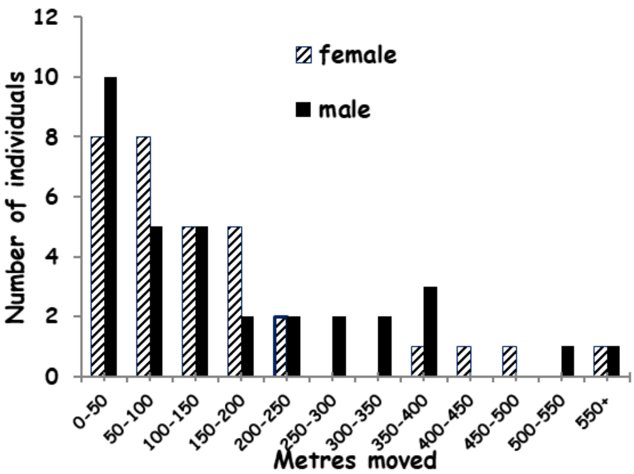

Fig. 1. Distance moved by 33 male and 32 female *Glis* from their nest box refuge to their winter hibernation site (located using radio collars).

Results

A total of 93 *Glis* had collars fitted. At best, the radio signal from the hibernaculum could be detected from almost 200 m whilst for others, deep underground or the other side of a large tree root could be heard from only ca. 25 m away. Thus some were easily located whilst others took many hours of searching and some

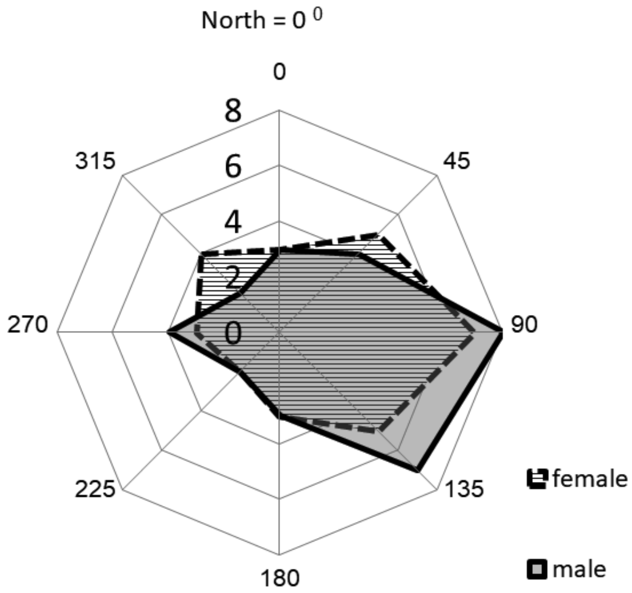

Fig. 2. Direction of travel from nest box to hibernacula by female and male *Glis*. Outer numbers denote compass angle of direction moved (0-315^0); angular rings denote number of individuals (0-8).

were never found. We postulate that this was because the collar had stopped working or had significantly changed frequency or the animal was sufficiently far from all the areas of search in the study site that we could not detect the signal. Sixty five individuals (70 %) were successfully located during the subsequent hibernation period; 33 male and 32 female (Table 1). More of the radio-collared individuals were found alive in subsequent years of monitoring during the active season (at least 84), indicating a minimum of 90 % of radio collared *Glis* had successfully hibernated and survived to re-enter a nest box. One was not recaptured for four years. On one occasion we were convinced that a buzzard (*Buteo buteo*) had swallowed a radio-collared *Glis* because the very faint radio signal located in a tree suddenly appeared more obvious, became very loud as a buzzard flew over the two field monitors, then disappeared never to be located again. That *Glis* was never again found in any nest box.

Exceptionally, individual spring records also indicated animals were found at great distances from their normal nest box. For example, an individual *Glis* (PIT tag no: 26677) found on the 5th May 2013 in box S17 with muddy feet and face (indicating that it had recently emerged from winter hibernation) was radio collared and released. It was next located on the 2nd June in box B10, over 500 m away. All the other captures during six years of its known lifespan were in B10 or the adjacent box, suggesting that it had hibernated, at least in that year, a long way from its normal range area. Two other animals found that spring in nest boxes had soil on the feet and face suggesting they had emerged from underground only a night or two previously; their subsequent recapture was in their usual nest box.

Ninety percent of female hibernacula located (males 75 %) were less than 250 m from the "home" nest box whilst the 90 % equivalent for males was 400 m (Fig. 1). There was no significant difference between males and females in the mean apparent distance moved ($t = 0.26$ with 63 df, $P = 0.799$). *Glis* were recorded moving in all directions (Fig. 2) although more animals moved to the east and southeast (15/32 and 12/33 respectively) than any other direction. There was no significant difference between sexes in the mean direction travelled to the hibernaculum ($t = 1.37$ with 62 df, $P = 0.175$) based on a circular regression model. The overall distribution of directions is significantly different from a uniform distribution (Rayleigh test $P = 0.017$), reflecting the preponderance of movements in a south-easterly direction.

We successfully excavated 34 hibernacula occupied by radio-collared *Glis*. An obvious entrance hole to the hibernaculum chamber was not the norm. We did not attempt some excavations because of unsuitable locations within complex tree roots, under woodpiles, under a concrete garage slab, within a badger set or judged to be very deep. We failed to locate the actual hibernacula in several instances despite changing the aerial array length and position and we abandoned those excavations. Sometimes during the excavation the hibernation cavities were found to be too deep. Other times the signal was being mysteriously and erratically diverted by large stones or heavy tree roots, or perhaps the *Glis* was moving while we were digging, making it impossible to accurately locate the hibernation cavity to examine the animal(s).

Out of the 34 successfully excavated hibernacula, 26 (76 %) contained only one *Glis*, five had two and three had three. Only one contained an adult female and her known marked young but two others had an adult plus one or two unmarked young.

Discussion

This is the first time a concerted effort in the U.K. has tried to examine where individual *Glis* go in order to hibernate. The results indicate that the distance an individual will move from its frequently used refuge to its hibernaculum varies greatly between individuals, from 5-550 m. We cannot be certain what happened to the other collared animals where we did not find the hibernation sites, although radio failure as well as potentially longer distance movements cannot be ruled out. It is also noteworthy that despite whatever "normal" mortality was occurring, at least 90 % of the adult (presumably more experienced) animals that were radio-collared were subsequently recorded post hibernation (even if some years later), even when their hibernaculum had been excavated. The direction of movement included every sector of the compass, though significantly more were recorded hibernating to the east or southeast of their main nest box. In autumn this might represent movement away from the setting sun or towards the rising sun, but without knowledge of the timing of the night time movements of *Glis* towards the hibernacula any cue is conjecture.

There are no caves in the study site; hibernation nests were found associated with rotten tree stumps, live tree roots, partly lifted root balls, with rabbit, fox or badger burrows (using their tunnel as a starting point for some further excavation) and sometimes mouse or rat holes appeared to have been enlarged. Since the *Glis* population has been present in the wood for at least 50 years, and in large numbers for a decade (Trout et al. 2015), it may be assumed that there are many holes and chambers available and individuals are not necessarily excavating new hibernacula each year. Several entrances and chambers may be found around a single large rotting tree root. Casual field observations consistently indicated that obvious entrance holes in the woodland floor suddenly became more numerous in the autumn. They were covered by leaves overwinter but open holes suddenly become obvious again in late spring. We have no hard evidence that individuals return to the same hibernaculum each year, but neither of the two individuals we radio-tracked twice, in two separate winters, returned to hibernate in the same place. We suspect this is the opposite of the communal cave hibernation reported in continental Europe by Kryštufek (2010).

There are several disadvantages to not having had sufficient resources to more precisely study the *Glis*. By not radio-tracking individuals during the whole active season, but instead relying only on nest box locations, it was not possible to demonstrate the true home range as indicated by Ściński & Borowski (2008). As nest boxes were not placed in a standard grid throughout the wood, presence in box(es) is unlikely to reliably estimate the true home range (as discussed by Brooks et al. 2012). The record of captures for each animal over its apparent lifetime revealed that the majority had been found in only one or two adjacent nest boxes and this was considered a reasonable central reference point. As individual *Glis* were only sporadically resident in any given nest box, we could not target particular individuals to collar, and could only choose older animals actually present during a box inspection. Natural mortality may have contributed to the failure to recapture 100 % of radio collared individuals in subsequent years, although we accounted for 90 %. In the extremely wet winter of 2013 we estimate that about 25 % of all hibernating *Glis* drowned in some parts of the wood; including three found dead and rotting in very wet hibernacula in clay soil.

Using the long-term monitoring history we found that *Glis* are most commonly located in their natal nest box, or only one or two boxes distant from that point, even when known to be alive for 5-12 years (Brooks et al. 2012). So it is reasonable to adopt the principal nest box as the centre of activity from which to move to the hibernaculum. Very few animals have otherwise been recorded moving large distances and then returning, as opposed to dispersing permanently from the natal nest. Other supporting evidence includes several instances where animals with soil covered faces were recorded in nest boxes in late spring, indicating recent emergence from an underground hibernation cavity. Their spring-time location was far from their natal nest box and these individuals soon returned to their natal nest box.

Our evidence suggests that very few *Glis* hibernate communally in this woodland. These results are similar to those of Jurczyszyn (2007) who found most of the cavities (77 out of 83, 92 %) were occupied by a single animal. In comparison, Morris & Hoodless (1992) found 1 × 1, 1 × 2 and 1 × 3 hibernating individuals whilst excavating radio-collared hibernating *Glis* in a different wood.

Collectively the evidence suggests that females do not teach their young precisely where to hibernate but they have to learn the process entirely by themselves. However, further research could be done through intensive monitoring with night vision equipment to indicate whether juveniles follow their mother to the ground. In contrast, caves in Europe have been reported to contain many, if not hundreds, of hibernating *Glis* (Polak 1997, Kryštufek & Flajšman 2007). It would be illuminating to know from where they have travelled and whether most remain underground all summer in a non-breeding year. We have put very long term collars on six already hibernating *Glis* (in the winter of 2016/17) to determine whether they hibernate for two winters and the intermediate (non-breeding) summer. Three (radios) remained underground all summer and during early winter 2017/18, so far giving a similar result to that of Bieber et al. (2009) for well-fed captive animals. We hope to track these animals in the active season of 2018 and find them again in nest boxes to confirm that they had successfully emerged after hibernating for 20 months.

The amount of economic damage and nuisance created by *Glis* in the U.K. indicates that management is increasingly necessary in buildings and also in some woodland situations (Trout & Mogg 2017). However, the current methods of live or kill trapping are not cost-effective with serious infestations (in houses) in England as repeated trapping periods are required even within one season (Trout & Mogg 2017) as well as annually. No evidence of effectiveness is available for putting traps in woodlands. A better potential long-term population control approach suggested by our results is to provide attractive cave-like artificial hibernacula in suitable locations near to the site of concern, whilst erasing simpler natural sites where practicable. This may encourage communal hibernation (copying the cave situation) thus concentrating the hibernating *Glis* where management can be undertaken at a convenient time during winter.

Our historical data (Trout et al. 2015) indicated that "missing" animals refuge somewhere during non-breeding years (i.e. are not found in our boxes anywhere in the wood during the summer) but subsequently re-appear in the trapping history at least 20 months later. This and the lack of communality in woodland hibernation has a practical consequence by complicating the planning for any short term, i.e. single year, pest control strategy. *Glis* population numbers can fluctuate greatly from year to year, making it extremely difficult to assess accurately the need for control and to plan precise control measures in advance. If the "wrong" year (i.e. non-breeding year with few adults apparently active) is chosen in advance to administer control it is likely to be very unsuccessful in impacting the actual *Glis* population alive and present at the time.

Conclusion

Glis in the U.K. may move short or long distances from a tree-based refuge to hibernate underground. Both sexes may move in any direction. The majority of individuals hibernate alone, unlike the cave communality reported abroad. Creating artificial, very attractive, hibernacula could create communality which would assist population control efforts where management is necessary. Careful advance planning for the timing of a control effort is required to overcome the issue of many *Glis* not appearing in non-tree flowering years, only to reappear subsequently. Demonstrating a twenty month long hibernation period would be a remarkable outcome for such a small mammal.

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