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RESEARCH PAPER

Hazel dormice use reed beds for nocturnal activity and daytime resting

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Abstract. This study presents empirical evidence elucidating the utilisation of reed beds by hazel dormice (*Muscardinus avellanarius*) during their summer activity phase. Historically characterised as an arboreal species confined to woodland and hedgerow habitats, the comprehensive assessment of this strictly protected species within reed beds and analogous wetland ecosystems across Europe has been lacking, presumably due to the presumption of their absence in such locales. This study aimed to employ radio telemetry to monitor hazel dormice and assess their utilisation of a reed bed compared to adjacent woodland for both nocturnal activity and daytime resting. To achieve this aim, eight hazel dormice were fitted with radio transmitters at the boundary between a reed bed and an adjacent woodland and tracked for a minimum of three consecutive nights. Results showed that the animals used the reed bed to a comparable extent to the adjacent woodland during their nocturnal activity. Furthermore, hazel dormice frequently chose resting sites in the reed bed during the day. Although the nesting and breeding behaviour within the reed bed was not thoroughly examined, the discovery of a hazel dormice nest suggests that hazel dormice construct summer nests within the reed bed habitat. Reed beds, particularly when interconnected with adjacent woodland, constitute an integral component of the habitat of the hazel dormouse, a previously overlooked fact. Hence, it is essential to include reed beds in strategies for conservation management and further research aimed at elucidating the habitat requirements of the hazel dormouse.

Key words: *Muscardinus avellanarius*, wetland, habitat, radio telemetry

Introduction

The hazel dormouse *Muscardinus avellanarius* is listed in Annex IV of the European Habitats Directive (Ludwig et al. 2022), which was established in 1992 and provides a strong legislative framework to prevent further decline of endangered species and habitats. Today, over a quarter of Europe's animal species are at risk of extinction (European Commission 2023). Species listed in Annex IV are under strong protection.

Until now, the presence of the hazel dormouse has primarily been evaluated within forest habitats and hedgerows, as the hazel dormouse is commonly described as a strictly arboreal species, which means its habitat is closely linked to woody plants (Bright et al. 2006, Schulz et al. 2013, Meinig & Büchner 2022). Especially forest edges, clear cuttings and hedgerows with a dense and species-rich shrub layer are considered optimum habitats (Foppen et al. 2002, Vilhelmsen 2003, Juškaitis 2007a). The hazel dormouse mainly feeds on non-woody plant

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components such as flowers, fruits and seeds (Juškaitis 2008). Relatively sparse woodland stands with a high diversity of woody and herbaceous plant species are considered ideal as they provide various food sources throughout the year (Bright & Morris 1990, Capizzi et al. 2002, Schulz et al. 2013).

Many studies indicate that the hazel dormouse is more flexible regarding habitat requirements than previously assumed (Juškaitis 2007b, Eden 2009, Goodwin et al. 2020). The hazel dormouse was also found in pure spruce and beech forests (Büchner et al. 2018), in gorse stands, heathland, birch scrub and coastal shrub vegetation (Chanin & Woods 2003) and even in the high altitudinal range of the Alps (Bertolino et al. 2016). In habitats without a species-rich shrub layer, hazel dormice can substitute insects or vegetative plant material for the lack of flowers and fruits (Juškaitis 2007a, Bertolino et al. 2016, Büchner et al. 2018).

Reed beds are currently not considered suitable habitats for the strictly protected hazel dormouse. Building on previous indications of the presence of hazel dormice in reed beds (Wipfler et al. 2020), the present study investigates whether reed beds are part of the habitat spectrum of the hazel dormouse. Preliminary investigations were carried out in 2020 to check for hazel dormice in other reed beds with nest tubes. The encouraging results suggested that dormice colonise reed beds if nest tubes are provided.

In the present study, the ranging and nesting behaviour of the nocturnal hazel dormouse was investigated using radio telemetry. We analysed the species' use of reed vegetation compared to woody vegetation. Eight dormice were fitted with radio transmitters and tracked for at least three days and nights to answer the following questions: 1) To what extent do hazel dormice use reed beds compared to woods during their nocturnal activity? 2) Do hazel dormice use reed beds as resting sites during the day?

Material and Methods

Study Area

The study was conducted in south-east Germany (49°47′ N, 11°01′ E) between May and July 2022. The study site incorporates a 1 ha big reed bed (*Phragmites communis*) located in the silted-up part of a quarry pond. The reed bed is surrounded by woody vegetation consisting of middle-aged trees of mainly willow (*Salix fragilis*, *S. purpurea*, *S. viminalis*), black alder (*Alnus glutinosa)* and aspen (*Populus tremula)* and various shrub species such as hazel (*Corylus avellana)*. The study site is surrounded by a sand and gravel extraction area, quarry ponds to the east and south, a railway line to the west, and agricultural land to the north. The northern part of the study area was flooded at the beginning of the study period and

Fig. 1. Radio transmitters (blue) were glued into the fur of the hazel dormice.

dried out during the summer. The size of the flooded area was mapped with a GPS device (Trimble Geo 7X) and digitised in QGIS software (version 3.4.10) for each session.

Capture and transmitter fitting

Radiotracking was carried out in four sessions during the active period: 20-23 May, 03-06 June, 15-18 June and 27-30 July 2022. Dormice were captured in self-made nest tubes (Wipfler et al. 2020), installed at the boundary between the reed bed and the adjacent woodland at a height of 1 m. Nest tubes were checked during the day. All dormice caught were weighed using a high-precision digital scale (model Archery-550, company 3 Data), and their sex was determined. Only adult hazel dormice weighing more than 17 g were included in the telemetry study. The study animals were fitted with a transmitter, which was carefully glued into the fur on the back of the animal (Fig. 1) using spirit gum (model Sauer Hautkleber 5020, company Manfred Sauer GmbH, located in Lobbach, Germany). Two types of transmitters were used (type V1, 0.37 g, company Telemetrie-Service Dessau, located in Dessau, Germany and type LB-2X, 0.31 g, company Holohil, located in Carp, Canada), both weighing less than 5% of the body weight of the hazel dormice.

A licence from the responsible governmental agency of Lower Franconia and approval of the Animal Welfare Official of the University of Bayreuth was available in advance (RUF-55.2.2-2532-2-1406-18).

Radiotracking

Between May and July 2022, 13 adult hazel dormice were found in the nest tubes, of which eight animals (three females and five males) were included in the study. Two animals escaped when the tube was opened, and three females with new-born litters (juveniles weighing < 5 g) were not included in the study. To observe the nocturnal activity, we tracked the study animals for 34 tracking nights (three to six nights per individual; Table S1). Animals were located through bearings at least once per hour. Observation of the nocturnal ranging behaviour began approximately one hour after sunset and ended between 4:00 and 5:00 a.m. Resting sites (daytime hiding places) were determined once per dormouse at midday.

As it was impossible to follow the study animals through the dense vegetation, we used triangulation from two positions outside the reed bed. Two observers stood at different positions outside the reed bed and located the respective study animal simultaneously by taking bearings using a receiver (ICOM-IC-R30) and a hand-held Yagi antenna (HB9CV with TH7). For each bearing, they recorded their position with a GPS device (Garmin eTrex Vista HCx) and the direction from which they received the strongest signal with a bearing compass. The intersection of the two bearings, corresponding to the position of the dormouse, was then determined in QGIS (version 3.4.10). A test transmitter (Telemetrieservice Dessau) was hidden at 30 different locations in the study area by an external field operator to test for the inaccuracy of the telemetric triangulation. The distance between the true position of the transmitters and the estimated position of the bearings (linear error) was, on average, 10.1 m. The average difference in angular direction (angular error) was 13°. To test whether the bearing inaccuracy of the bearings distorted the result of the study, i.e. the number of fixes inside and outside the reed bed, a 10 m wide buffer zone (5 m each inwards and 5 m outwards) was placed around the reed bed. The ratio of fixes in both parts of the buffer zone was about the same (n = 59 inside and n = 62 outside). Therefore, it can be assumed that approximately the same number of fixes were erroneously inside and outside, and all fixes were included in the further analysis.

Habitat-use analysis

The habitat-use analysis was carried out in three steps. First, all nocturnal fixes inside the reed bed, the adjacent woodland and 'other' vegetation were identified in QGIS. The adjacent woodland consisted mainly of semi-natural hedgerows and shrubs. 'Other' vegetation included the railway line, sand and gravel extraction sites and agricultural land. To test for significant differences between the number of dormouse fixes inside the reed bed and woody vegetation, we tested the data for normality and conducted a paired T-test with a significance level of 5%.

To describe how far an animal moved during the night, we determined the radius of nocturnal activity. This parameter was measured as the straight-line distance between the animal's resting site and the fix furthest away from the resting place (Bangura 1988, Bright & Morris 1992). The radius of nocturnal activity was determined for each animal and each night. In the second step, the maximum radius was calculated for each animal.

In a third step, we calculated the availability of reed vegetation within the maximum radius of nocturnal activity of each hazel dormouse. This calculation was accomplished by drawing a circle with the maximum

Table 1. Usage (based on the number of fixes within the reed bed) and calculated reed availability (based on the proportion of the reed area within the radius of nocturnal activity of each hazel dormouse).

Dormouse	Use of reed bed (%)	Availability of reed (%)
M2	100.0	63.6
F3	46.9	19.0
F1	60.6	32.3
M3	15.0	18.5
M1	35.4	22.4
M5	46.5	31.9
M4	42.9	6.8
F2	0.0	21.0
Mean (26 nights)	42.1	27.6

radius of nocturnal activity around each resting place and calculating the percentage of the area covered by reed vegetation within the circle for each study animal. The availability calculated this way was then compared with the usage of the reed bed (percentage of nocturnal fixes inside the reed bed divided by the total number of fixes of the night) for each hazel dormouse using a Mann-Whitney U test. If the usage was significantly higher than the availability, this indicates that the respective animal had a preference for the reed bed (Johnson 1980).

Table 2. Number of daytime fixes of hazel dormice in the reed bed, adjacent woodland and nest tubes and average values per dormouse.

	Reeds	Woods	Nest tubes
Daytime-fixes	8	12	6
Average value per dormouse	42.5%	45.0%	12.5%

In addition, we analysed the nest material of all nests built by hazel dormice in the nest tubes at the boundary between the reed bed and adjacent woodland. Nests were separated by hand, and the proportion of the different plant materials was determined using volumetric estimation. All analyses were conducted using R-Studio software (version 4.1.3) (R Foundation 2024).

Results

Habitat use

Hazel dormice used reed beds to a similar extent as the adjacent woodland. At night, 41.1% of the fixes

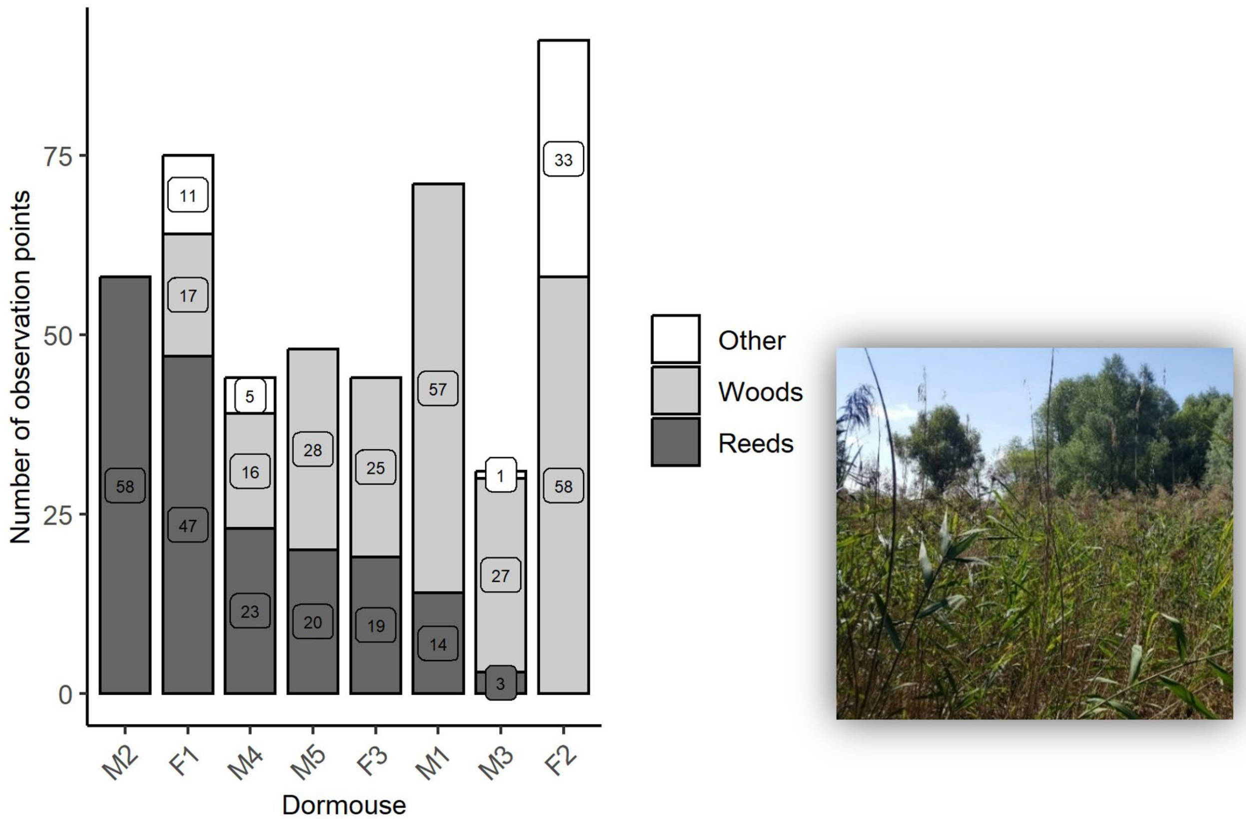

Fig. 2. Number of radio telemetric fixes in the reed bed, adjacent woodland, and other vegetation of the eight hazel dormice tracked during the night.

were found in the reed bed, 50.7% in the adjacent woodland and 8.2% in other vegetation (Table S2). Six of eight animals were observed in the reed bed and the woody vegetation. One hazel dormouse was recorded only in the reed bed, and one animal was never found in the reed bed but remained exclusively in the woodland and on the adjacent sandy area (Fig. 2). There was no significant difference in the number of fixes recorded in the two habitat types, reed bed and adjacent woodland, during the night (T-test, $P > 0.05$, n = 8).

The maximum radius of nocturnal activity of the study animals was between 34 m and 163 m around the resting sites of the previous day (Table S3).

The number of nocturnal fixes in the reed bed was significantly higher (mean 42.1%) than the calculated availability of reed vegetation in the surrounding of the hazel dormice's nests (mean 27.6%) (Mann-Whitney U test, $P = 0.046$, n = 26 nights). This result indicates that the hazel dormice used the vegetation surrounding their nests and had a night-time preference for the reed bed. Six of eight animals spent more time in the reed bed than was calculated by availability (Table 1, Fig. S1).

Resting sites

Hazel dormice also used the reed bed as a resting site during the day. The study animals could be recorded for one to six days, resulting in 26 daytime fixes. On average, the animals selected 42.5% of their resting sites in the reed bed, 45.0% in the adjacent woodland, and 12.5% in the nest tubes at the reed-woodland boundary (Table 2). Four hazel dormice were recorded in the reed bed during the day (eight out of 26 fixes; Table S4).

During the first session, the northern part of the study area was flooded (Fig. S2). One hazel dormouse used the flooded area with willow vegetation (*Salix* spp.), with a water level of about 30 cm, for several days and nights. Two other individuals were observed there once. During the summer, the area dried out completely, so activity in the flooded area could not be observed during the later sessions.

The main component (44%) of the 21 nests found in the nest tubes was the reed (*P. communis*) (Fig. S3). Besides reeds, willow leaves were a popular nesting material (32%). Other materials such as tree bark (18%), other leaves (4%) and moss (2%) were found less frequently.

Fig. 3. Daytime resting sites of hazel dormice inside the reed bed (orange), adjacent woodland, and nest tubes (white circles), including a summer nest found inside the reed bed.

Additionally, a nest of a hazel dormouse was found inside the reed bed (Fig. 3). It could be detected because a study animal (M2) lost its radio transmitter inside the nest. Only male hazel dormice were observed in the reed bed during the day. Female hazel dormice did not use the reed bed for resting. Two females selected resting sites in the adjacent woodland, and one female was repeatedly found in the same nest tube at the boundary between the reed bed and the adjacent woodland (Fig. 3).

Discussion

Reed beds have traditionally not been considered a relevant habitat for the hazel dormouse. This study shows that hazel dormice used the reed bed to a similar extent as the adjacent woodland (41% reed, 50% woods) during the night and also for resting during the day. These findings complement single observations of dormice in a reed bed in Slovenia (Kryštufek cited in Juškaitis & Büchner 2010) and in the reed belt of Lake Constance (Berthold & Querner 1986) and demonstrate that reed beds connected to woodland should be considered as part of a hazel dormice habitat during the summer season.

Protection from predators

Reed vegetation is likely to provide hazel dormice with good protection from predators. On the banks of water bodies, reed beds are often submerged and are difficult for predatory mammals to access (Schmidt et al. 2023). In addition, numerous authors have shown that hazel dormice selectively choose spiny and thorny vegetation as nest sites because they are difficult for their predators to access (Berg & Berg 1998, Juškaitis & Remeisis 2007, Wolton 2009). Within the reed bed, hazel dormice exhibit effective camouflage, rendering them inconspicuous to aerial predators like owls (*Strix aluco*, *Aegolius funereus*, *Bubo bubo*) and birds of prey (*Buteo buteo* or *Accipiter nisus*) that hunt hazel dormice (Juškaitis 2008). Other predators, such as the weasel (*Mustela nivalis*) or stoat (*Mustela erminea*), are also typically not found in reed beds (Niethammer et al. 1993).

Competition avoidance

Reed vegetation may provide a competitive advantage over wood and yellow-necked mice (*Apodemus sylvaticus* and *Apodemus flavicollis*). Both species are nocturnal and widespread in woods and hedgerows (Marsh et al. 2001). Competition is mainly based on the use of nesting sites and food (Juškaitis & Büchner 2010). The yellow-necked mouse is significantly larger and stronger than the dormouse and can displace it from nest boxes and tubes (Marsh & Morris 2000, Lang et al. 2022), sometimes even killing it (Juškaitis & Büchner 2010). Studies in Great Britain and our own observations in the study area showed that hazel dormice abandoned nest sites occupied by a wood- or yellow-necked mouse (Marsh & Morris 2000, Juškaitis 2008, Wipfler et al. 2020). In contrast to nest tubes in hedgerows and forest edges, nest tubes in the reed bed have not yet been observed to be taken over by *Apodemus* species.

It can be assumed that hazel dormice are better adapted to climb and move within the reed vegetation than *Apodemus* species. The first toe of the hazel dormice is opposable to the other toes, similar to a thumb. The fifth toe can also be spread out at an almost right angle (Juškaitis & Büchner 2010). This anatomy allows the hazel dormouse to grasp thin stems and climb vertically on reed stems.

Food sources

Hazel dormice forage at night, moving specifically towards food sources (Bangura 1988, Bright & Morris 1991, 1992). Seven out of eight hazel dormice were recorded in the reed bed at night, suggesting that hazel dormice find food in the reed vegetation. Reeds have not yet been reported as a food plant for the hazel dormouse, but the reed vegetation in the study area contains a variety of different insect species, such as nocturnal butterflies, caterpillars, terrestrial snail species and water molluscs (C. Strätz, unpublished data). Juškaitis (2007a) states that insects, molluscs and earthworms belong to the food spectrum of the hazel dormouse. Whether these represent a food source for the hazel dormouse in reed beds needs to be verified by faecal analyses in the future.

Resting sites

The discovery of a radio transmitter in a hazel dormouse nest in the reed bed provides evidence that hazel dormice build summer nests in the reed vegetation. So far, hazel dormice have only been found in already existing bird nests (Berthold & Querner 1986) or nest tubes in the reed bed (Wipfler et al. 2020). The nest found in this study was made of reed material and was perfectly camouflaged. It is plausible that hazel dormouse nests within reed beds are considerably more challenging to detect than summer nests in hedgerows, which remain visible during winter when foliage is absent. This potential difficulty in detection may be why hazel dormice in reed beds has not been noticed so far.

As we used radio telemetry to record the resting sites of the hazel dormice, we do not have detailed information on nesting and breeding behaviour within the reed bed. However, it was noticeable that only males selected resting sites in the reeds during the day. A possible explanation could be that male hazel dormice are not involved in raising the young (Juškaitis & Büchner 2010) and are less sedentary than females (Bangura 1988). Female hazel dormice are known to choose nest sites in particularly dense and protective vegetation, which provides a high diversity of food plants to feed the young (Juškaitis et al. 2013). Therefore, the female study animals probably selected resting sites in the adjacent woodland or stayed in the nest tube.

Nest material in the nest tubes

Reed was found to be a preferred nest material. In the study area, it was found as the main component (44%) of the hazel dormouse nests in the nest tubes. Although the nest tubes were not hanging in the reed bed, the animals collected reed leaves, flower panicles and stems and used them to build their nests. They probably chose the reed material because it is particularly water-repellent and has good insulating properties. It has been shown that hazel dormice build nests with good insulation, saving about 55% of the energy required outside the nest (Juškaitis & Büchner 2010).

Flooded areas

Our telemetric observations suggest that hazel dormice use flooded areas if the vegetation is dense enough and provides climbing opportunities. For several days and nights, one hazel dormouse colonised the flooded area dominated by willow (*Salix* spp.). Similar observations were made at Lake Constance, where two hazel dormice were found in the reed belt at water levels of 30 cm and 50 cm (Berthold & Querner 1986). Furthermore, a hazel dormouse nest was found in sedge vegetation (*Carix riparia* and *Carix auctiformis*) on a lake shore with a water depth of more than 100 cm in 2020 (V. Lissek, pers. comm.).

Conclusion

This study shows that reed beds, particularly when associated with adjacent woodland, constitute a habitat component for the hazel dormouse *M. avellanarius*. Hazel dormice deliberately use reed vegetation to range during the night and rest during the day. To comply with the European Habitats Directive, which requires strict protection of the hazel dormouse and its breeding and resting sites, it is important that government agencies and institutions incorporate the increased knowledge of reed beds as a hazel dormouse habitat into their conservation programmes and monitoring.

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Author Contributions

R. Wipfler and Ch. Strätz planned the experimental design and conducted the fieldwork. M. Steinbauer was involved in the study's conception and supervised its findings. All authors discussed the results and contributed to the final manuscript.

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Supplementary online material

Table S1. Data of study animals radio-tracked between May and July 2022.

Table S2. Percentage of radio telemetric fixes of hazel dormice in the reed bed, adjacent woodland and other vegetation during nocturnal activity.

Table S3. Average and maximum radius of nocturnal activity (= maximum distance travelled from the resting places in one night) of hazel dormice.

Table S4. Number and average percentage of resting sites in the reed bed adjacent woodland and other vegetation based on radio telemetric fixes during the day.

Fig. S1. Nocturnal activity in the reed bed (median 40.6%) compared to the calculated availability of reed vegetation surrounding the hazel dormice's nests for all study animals (left) and per individual hazel dormouse (right).

Fig. S2. Radio telemetric fixes in the flooded area (water depth > 30 cm), which covered parts of the reed bed (orange) and willow bushes (green).

Fig. S3. Proportion of nest material found in the nest tubes (n = 21) located at the boundary between the reed bed and adjacent woodland including photos of the main components reed a) and willow leaves b).

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