POPULATION DYNAMICS, HABITAT USE AND TELEMETRY STUDIES OF *MYOMIMUS ROACHI*

MASTER THESIS

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ABSTRACT

The Mouse-tailed Dormouse *Myomimus roachi*, probably the rarest dormouse species in Europe, occupies a special place in the continent's fauna. It has been known to exist for less than a century and its distribution is limited to Thrace with localities in Turkey, Bulgaria and eastern Greece. It is protected by the EU Habitats Directive. In 2017, Bulgarian researchers rediscovered the species north of the village of Levka, leading to an intensive monitoring programme. This includes the control of over 70 nest boxes and the placement of live traps in a 48-hectare study area characterised by dense shrubs and oak trees. This paper reports on a telemetry study carried out from September to October 2022 with the aim of calculating the home range of the species using the Minimum Convex Polygon method and Fixed Kernel Density Estimation. In addition, habitat parameters were recorded and their significant effects on the probability of catching the species were investigated using binary logistic regression. This study also analysed long-term monitoring data (2019 – 2022) to calculate an occupancy model and estimate the population size using the POPAN parameterisation. A Jacobs index was calculated using both monitoring and telemetry data. Population dynamics were analysed from the monitoring data. One individual could be captured for telemetry. The male’s MCP100 had a home range of 0.2252 ha, while the K65 had a home range of 0.1907 ha. This is rather small compared to other dormouse species. The Jacobs index showed a preference of the species for wooded and shrubby areas in the monitoring data and for open land in the telemetry data. The data showed a significant weight gain of adult males, juvenile males and juvenile females over the season, with an almost balanced sex distribution in 2021 and 2022, but males dominating in 2019 and 2020. The dominance of juveniles and adults in the population showed annual variation. The maximum population size was estimated at 77 ± 54 individuals in 2021. Survival rates ranged from 0.17 to 0.48, suggesting intense predation during hibernation. The occupancy model showed higher occupancy and detection rates than empirical data, highlighting the distribution of the species. The study also found that individual *M. roachi* can live for at least four years. The results suggest that qualitative variation in habitat may influence population reproduction and demography, while variation in sex structure may be related to sexual dimorphism in dispersal. Our findings conclude that the species acts as a boundary species between forest and open land, and the results provide important insights into the ecology of the species.

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1 Introduction

The International Union for Conservation of Nature (IUCN) currently classifies 27% of all recorded mammals on the Red List as Critically Endangered, Endangered, Vulnerable or Near Threatened (IUCN 2022). One of the main causes of species extinction is habitat loss and fragmentation due to human activities. There is a global trend towards species loss, leading to changes in the composition of species communities (Schmid & Pröll 2020). This increasing global loss of biodiversity is considered to be one of the major challenges facing humanity (IPBES 2019). The cause of a species' decline cannot always be identified. Nocturnal mammal species, especially rodents, are considered difficult to record (Vaterlaus 1998) and data gaps are inevitable. For some species, there is insufficient data to determine the conservation status of the species.

The situation is similar for the Mouse-tailed dormouse (*Myomimus roachi*). *M. roachi* is considered one of the rarest and least studied mammals of the western Palearctic (Nedyalkov et al. 2018). It continues to decline rapidly in Europe. *M. roachi* has a relatively short, almost bare tail. The whiskers are also quite short at about 27mm. The fur of this species is rather shaggy with short hairs. Adults have an ochre upperpart with occasional black hairs on the spine extending to the base of the tail. The belly is creamy grey. The fur on the lower jaw is yellowish cream. The hind feet of adults are slightly darker than those of subadults. The ears are grey, becoming almost blackish at the tip (Kryštufek et al. 2005a). The current distribution of *M. roachi* is one of the smallest among rodents. Most of its range is in Thrace, with localities in Turkey, Bulgaria and the eastern part of Greece (Kryštufek et al. 2005a). The range extends from the northernmost site near Nesebâr on the Bulgarian Black Sea coast to the southernmost record on the Mediterranean coast in Turkish Thrace (Kryštufek et al. 2005a).
M. roachi prefers agricultural semi-open to open areas with a steppe character (Kryštufek et al. 2005a, Milchev & Georgiev 2012). For example, the species is found in orchards, vineyards and oat, wheat, and maize fields (Nedyalkov et al. 2018, Popov 2015, Peshev et al. 1960). *Crategus sp.*, *Pirus malus*, *P. communis*, *Rubus sp.* (Kryštufek et al. 2005a) and farmland with old sparse trees (oak, peach and walnut) are also preferred (Nedyalkov et al. 2018). The main herbs and grasses that serve as habitat for M. roachi are *Setaria viridis*, *Trifolium arvense*, *T. diffusum*, *Xeranthemum annuum*, *Centaurea cyanus* and *C. diffusa* (Peshev et al. 1960). According to Buruldağ & Kurtonur (2001), *M. roachi* feeds on insects, spiders, snails, lizards, fruits, sunflower seeds and wheat in Anatolia. The species was initially thought to be mainly terrestrial/bottom dwelling, as only specimens caught in the trap set on the ground were initially recorded (Peshev et

al. 1960). It is now considered to be mainly arboreal, as it has been caught mainly in trees in Turkey since the 1970s and 1980s (Kurtonur & Özkan 1990, Buruldağ & Kurtonur 2001).

In Bulgaria, the current distribution is limited to the south-eastern area near the Turkish border (fig. 1). Traditional agriculture is found here, although it is in decline. In the industrialised regions of Stara Zagora, Radnevo, Maritsa Iztok, parts of the habitat have already been destroyed by local infrastructure (Popov 2015).

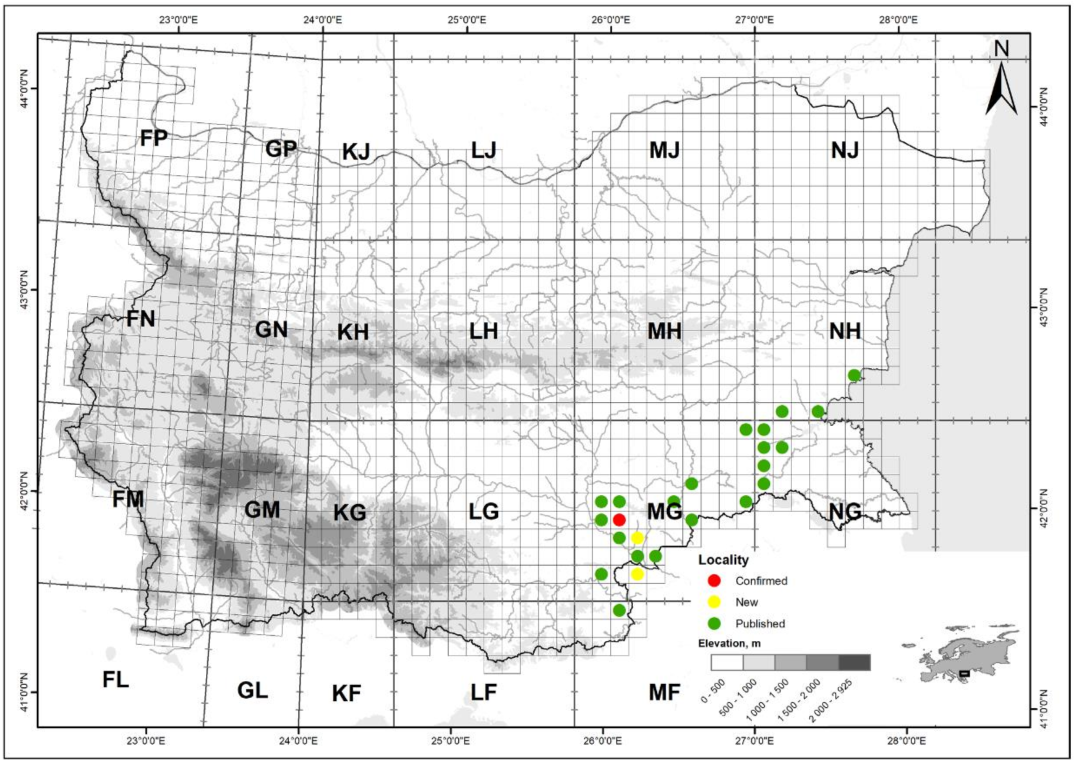

Figure 1: Distribution of *M. roachi* in Bulgaria. From Nedyalkov et al. (2018).

Little is known about the biology of this species. In 2001, however, some information on the life history of the species was obtained from five captured animals and their offspring. The animals were observed in Turkey under semi-natural conditions in a large outdoor cage in an orchard (Buruldağ & Kurtonur 2001). During the short active period from April to September, *M. roachi* breeds only once, with litter sizes ranging from 5-9 young. The first young are born at the end of June (Nedyalkov et al. 2022). Males do not emerge from hibernation until the end of April (24th April - earliest recorded). Nedyalkov et al. (2022) observed summer dormancy. Hibernation usually starts in the first half of September (Nedyalkov, pers. comm. 2022).

Overall, there has been a significant decline of the species throughout its range (Krystufek et al. 2009). Its current status, according to the IUCN (2022), is listed as vulnerable. *M. roachi* is listed by the European Union in Annexes II and IV of the Habitats Directive as a species of Community interest requiring strict protection, for whose conservation special protection areas must be designated by Member States (EUNIS - Site factsheet for Sakar 2023).

The aim of this study was to investigate the home range and habitat use of *M. roachi* in its natural habitat and to identify important habitat features. In addition, long-term monitoring data were analysed in terms of occupancy, population dynamics and structure, population size and sampling methods. Knowledge of *M. roachi* in its natural habitat is limited, and the results of this study should contribute to a better understanding of the requirements and ecology.

This work aims to answer the following research questions:

01. Where do the animals retreat to for hibernation?
02. What is the size of the home range of the animals?
03. Which habitats are preferred by *M. roachi*?
04. What is the detection rate of the methods used and what proportion of the test sites are occupied?
05. What is the estimated population size and what are the population dynamics and structure?
06. Which of the two detection methods is more successful?

2 Material and methods

2.1 Study area

The study area is located in the south-eastern part of the Balkan state of Bulgaria (fig. 2). It is located north of the village of Levka, and the closest larger city is Svilengrad 15 km west. The study area is located in a Natura 2000 site with the code BG0000212 and is surrounded by fields and a peach orchard in the southern part. The area contains a total of 38 species of conservation concern, of which 16 are mammals. This protected area also contains 15 habitat types. The entire Natura 2000 site covers an area of 13,2117 ha (EUNIS -Site factsheet for Sakar 2023). Our study area covers an area of approximately 48 ha. The mammal species present in the study area include *Myomimus roachi*, *Glis glis*, *Dryomys netidula*, *Apodemus flavicollis*, *Mus macedonicus*, *Crocidura suaveolens*, *Sus scrofa*, *Capreolus capreolus*, *Lepus europaeus*, *Felis silvestris*, *Martes foina*, *Meles meles*, *Canis lupus* and *Canis aureus*.

Grazing land, occasionally visited by cattle, is found in the northern part. The area lies in the continental Mediterranean climate zone (Ivanova & Stojanovska 2019). Summers are hot and winters mild, with occasional sub-zero temperatures (fig. 3). The uncultivated open areas in the study area are dominated by dry grasslands. Christ's thorn (*Paliurus spinachristi*) is a common shrub. The dominant tree species are oaks (*Quercus spec*.).

The area had been used as grazing land for livestock. However, use has declined since 1991/1992 and many areas are no longer in use (Milchev & Georgiev 2012). Used farmland often produces wheat, sunflowers, fruits, vegetables or tobacco.

Figure 2: Top: Location of the study area within Europe. bottom: Closer look on the study area. Source: Google earth

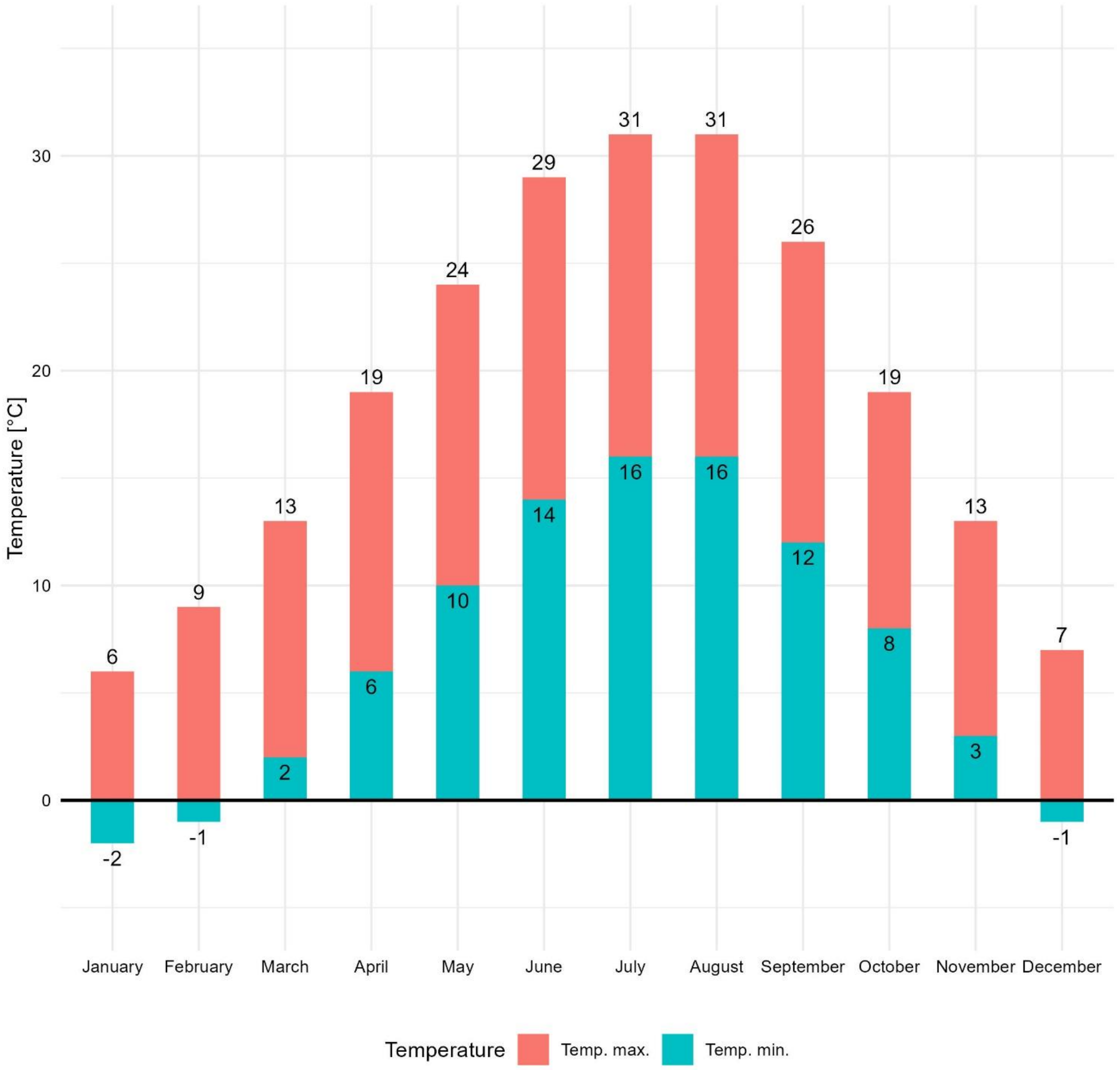

Figure 3: Annual temperature mean minima and maxima for Levka in south-eastern Bulgaria. (Source: NOAA https://www.noaa.gov/)

2.2 Study period of fieldwork

The fieldwork started on 12th September 2022 and lasted until 20th October.

Trapping

Traps were first set on the afternoon of 12th September and removed on the morning of 15th September (tab. 1).

Table 1: Overview of the trapping nights in the study area in south-eastern Bulgaria in September 2022. A total of 300 trapping nights were conducted.

Number of nights	Date	Number of traps
1	12. – 13.09.2023	100
2	13. – 14.09.2023	100
3	14. – 15.09.2023	100

Checking Nest boxes

A total of 76 nest boxes were checked several times a week, but not at fixed intervals. These nest boxes were checked from 12th September to 20th October.

Telemetry

The first day of telemetry was 15th September and the last day was 9th October. There were nine telemetry sessions during these weeks (tab. 2).

Table 2: Date and time of telemetry days and number of location records during the study period.

Start date	Time	End date	Time	Locations
15.09.2022	22:50	16.09.2022	07:00	8
16.09.2022	20:50	17.09.2022	07:00	10
22.09.2022	20:40	23.09.2022	07:00	10
23.09.2022	21:00	24.09.2022	07:00	8
01.10.2022	20:45	02.10.2022	06:00	9
02.10.2022	20:55	03.10.2022	06:35	10
03.10.2022	20:15	04.10.2022	05:30	8
08.10.2022	20:15	09.10.2022	00:40	5
09.10.2022	20:40	10.10.2022	23:40	4

Habitat data

Specific habitat parameters were recorded all day on 18th and 19th October in the environment of the trap sites and nest boxes.

Long-term monitoring

Long term monitoring also plays an important role in the study area (Nedyalkov et al. 2022). By means of trapping and checking nest boxes, animals have been recorded and marked by microchipping during the active season of April – November in this study area since 2019 (Nedyalkov et al. 2022). Only animals heavier than 10 g get microchipped (Nedyalkov et al. 2022).

2.3 Collecting data and handling animals

It is important to note that the methods for capturing animals described below have been used by Dr Nedyalkov since 2019.

During the field work of this thesis, animals were captured by trapping and checking nest boxes to

01. be equipped with radio collars for telemetry,
02. but also to record data for the monitoring programme.

Data such as date of capture, location of capture, sex, chip number and weight were recorded.

2.3.1 Trapping

Three different types of traps were used: The Longworth trap (NHBS, Totnes, UK), the Sherman trap (H. B. Sherman Traps Inc., Tallahassee, USA) and wooden DeuFa traps (DeuFa GmbH, Neuburg, Germany) (fig. 4). Traps were set randomly. A total of 300 trapping nights (100 traps x 3 nights) were attempted to catch the animals. Corn flips and apple pieces were used as bait in all traps. The sampling is always the same (fig. 5). The traps are often placed on trees where nest boxes also hang. In principle, several traps (usually three to four) are placed at one site. Half of them are placed on the ground and the other half on the trees (at a height of 1.5 - 2 m). The bait is the same for all traps. The traps are set in the afternoon before dusk. The next day, at dawn, the traps were checked. In some cases, nesting material (dry grass) was placed in the traps to protect the animals from the cold.

Figure 4: Wooden traps (left) and green aluminium Longworth traps (right). Picture: H. Queckenstedt

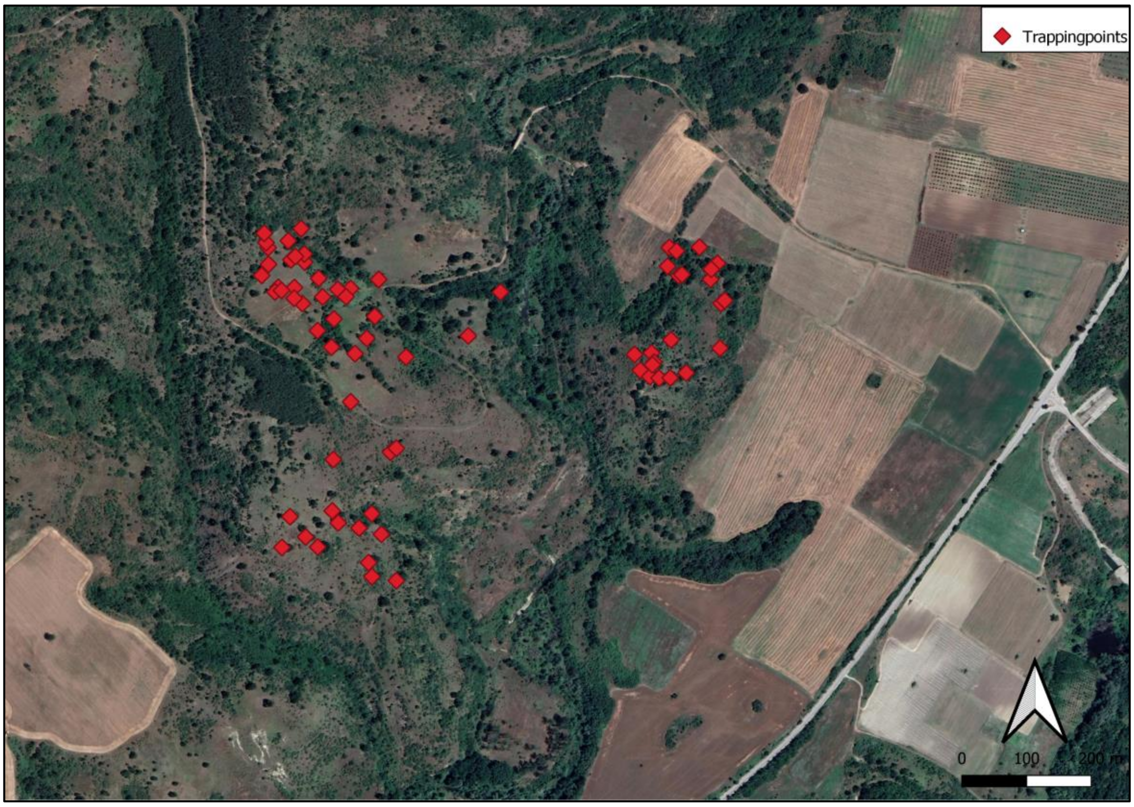

Figure 5: Trapping locations within the study area.

2.3.2 Nest boxes

Another way to capture animals is to check nest boxes. The animals usually retreat to these during the day. These nest boxes are randomly distributed throughout the study area on trees. A total of 76 nest boxes have been placed within the study area (fig. 6).

During the study period, nest boxes were checked much more frequently than traps were set. In fact, the nest box checks were several times a week.

The entrance and exit holes had to be closed before a nest box could be opened. This ensured that the animals could not escape through the opening. The willingness of the animals to escape was mainly determined by the time of the control. The earlier in the morning the more agile the animals, the later in the day the more dormant they were.

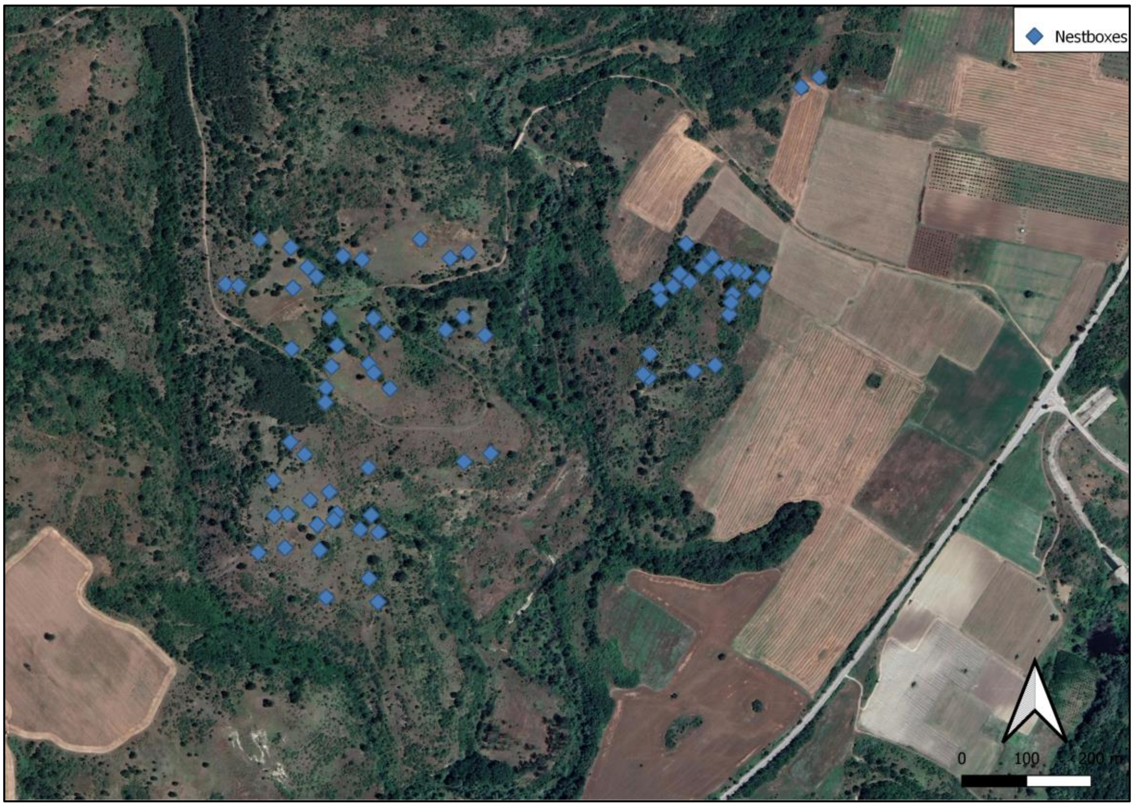

Figure 6: Nest box distribution within the study area.

During the check of the nest boxes in October, *M. roachi* nest material was removed from the boxes, if present, and weighed (fig. 7). This was done to understand the size of the nests.

Figure 7: Nest material of *M. roachi* was removed from a nest box and weighed to compare nest weights. Picture: H. Queckenstedt

2.3.3 Handling the animals

After an animal had been captured using one of the two methods described, it was placed in a plastic bag. This was done to allow the animal to rest for a short time and to be handled properly. Once in the bag, the animal was checked to see if it was microchipped or not (fig. 8). If the animal was chipped, an entry was made in the digital register. If the animal was not chipped, it was implanted with a chip if it met the requirements of at least 10 g in weight. Animals that were too small to be microchipped were only weighed and their sex determined. Animals were weighed in the bag and the weight of the bag was subtracted.

Figure 8: *Glis glis* is placed in a plastic bag for proper handling and checking whether it was microchipped or not. Picture: H. Queckenstedt

In addition to plastic bags, small wire cages were also used. If an individual was considered suitable for telemetry, it was transferred from the bag into the small wire cage and then safely transported in a plastic box. The covered box was kept in a cool place until the transmitter could be started. The animals were provided with water and food (e.g. fruit or insects).

Applying collars for telemetry

The collars were attached at our accommodation in the village of Levka. The animals were given a short anaesthetic. The volatile anaesthetic Isoflurane was administered to the animals by inhalation. In addition to being fitted with a collar, the animal was examined for parasites, which were collected and transferred to a container. Knowing the weight of the animals is very important as the total weight of the transmitter collar must not exceed 5% of the total weight of the animals to avoid any adverse effects (Ryan 2018). As the anaesthesia does not last too long, precision and speed was required. Whenever possible, faecal samples were collected and transferred to Eppendorf tubes containing ethanol.

Figure 9: Upper picture: Transmitter with antenna. Bottom picture: The anaesthetised male M2 immediately after application of the transmitter. Picture: H. Queckenstedt

The transmitters used in this study were the BD-2CT model manufactured by Holohil (Holohil System Ltd, Ontario, Canada) (fig. 9). The transmitters weigh approximately 1 gram and have an expected lifetime of approximately 40 days. The small transmitter is attached to a thin wire and placed around the animal's neck. A plastic tube protects the animal from injuries and cuts caused by the wire. The two ends of the wire collar are secured with a small clamp to prevent movement. Any excess wire must be cut off. It is important to make sure the collar fits perfectly. If it is too loose, the animal may remove it or gets a paw caught in it. It also increases the likelihood of the collar getting caught on a branch. On the other hand, the collar should not be too tight as this can cause serious breathing problems or other harm (Zschille et al. 2012; Zschille et al. 2008). As our study period was at the height of winter preparations, we also had to take into account that the animals would gain weight. After several checks to ensure that the collar was correctly fitted, the awake animal was placed in a plastic wake-up box and not examined again until it was released at the trapping site.

2.3.4 Habitat data

Habitat data were recorded (Goodwin et al. 2018, Marteau & Sarà 2015) at each nest box and trapping site by us on two days during a complete walkover of the study area (tab. 3). These data were recorded to determine if there was a statistically explainable relationship between the conditions at the sampling site and the catchability of those sites. Data were collected in a 1 m radius around each sampling point and in a 10 x 10 m transect. The transect was perpendicular to the centre of each sampling point. This resulted in a parameter collection of 5 m in each direction.

Table 3: Recorded Habitat parameters in the vicinity of nest boxes and trapping sites. Parameters were defined according to Goodwin et al. (2018) and Marteau & Sarà (2015).

Parameter	**Description**
1 m radius around trap/nest box	
Number of shrub species	Shrub species (< 2 m height) count within the ring
Shrub stem density	Live Shrub stem (< 2 m height) count at ground level within the ring
Number of woody species (NWS)	Woody species (< 2 m height) count within the ring
Woody stem density (WSD)	Live woody stem (< 2 m height) count at ground level within the ring
10 m transect from trap/nest box	
Overstory tree dispersion (OTD)	Distance (m) from trap to nearest overstory tree
Overstory tree size (OTS)	Circumference (cm) of nearest overstory tree
Tree stem density (TSDe)	Number of tree stem > 7.50 cm in circumference
Tree stem size (TSS)	Circumference (cm) of nearest tree stem
Soil surface exposure (SSE)	Percentage of points with soil exposure, within the transect

2.4 Telemetry technology

Each of the transmitters has an individual frequency that can be picked up by a receiver in combination with a four-element Yagi-antenna (Followit AB, Lindesberg, Sweden) (fig. 10, left). The antenna captures the signal from the animal's transmitter collar and relays it to the receiver. This ensures that the correct transmitter - and therefore the correct animal - is located.

Figure 10: Left: The antenna used for telemetry; right: the receiver used for telemetry. Both are connected by the cable supplied. Picture: H. Queckenstedt

The receiver used was a Followit RX-98E (Followit AB, Lindesberg, Sweden) (fig. 10, right). The receiver has an adjustable gain. The lower the gain, the closer the receiver is to the transmitter. In this way, animals could be located to within a few metres.

2.4.1 Telemetry in the field

The method used to locate the animals in this thesis is called homing-in. Another common method of telemetry is triangulation (Kenward 2001) (fig. 11). By constantly reducing the receiver’s gain and following the strongest signal, it is possible to determine the location of the animal very accurately with homing-in. Avoiding disturbance of the animal is particularly important during active tracking, as this can affect the data by changing the animal's behaviour. If the location of the animal could be determined without doubt, the point was recorded with a Garmin GPS device (Garmin Ltd, Olathe, USA) and recorded in the data sheet (appendix 1). If an animal is active, the change in gain on the receiver is a reliable indicator. If the gain fluctuates or the signal suddenly disappears and is picked up in a different direction, the transmitter is likely to be moving. On the other hand, if the gain increases steadily on approach without any change, it can be assumed that the transmitter is stationary. The aim was to determine the location of each animal every hour. Only records separated by at least 1 hour were included in the analyses to keep autocorrelation to a minimum (Rooney et al. 1998).

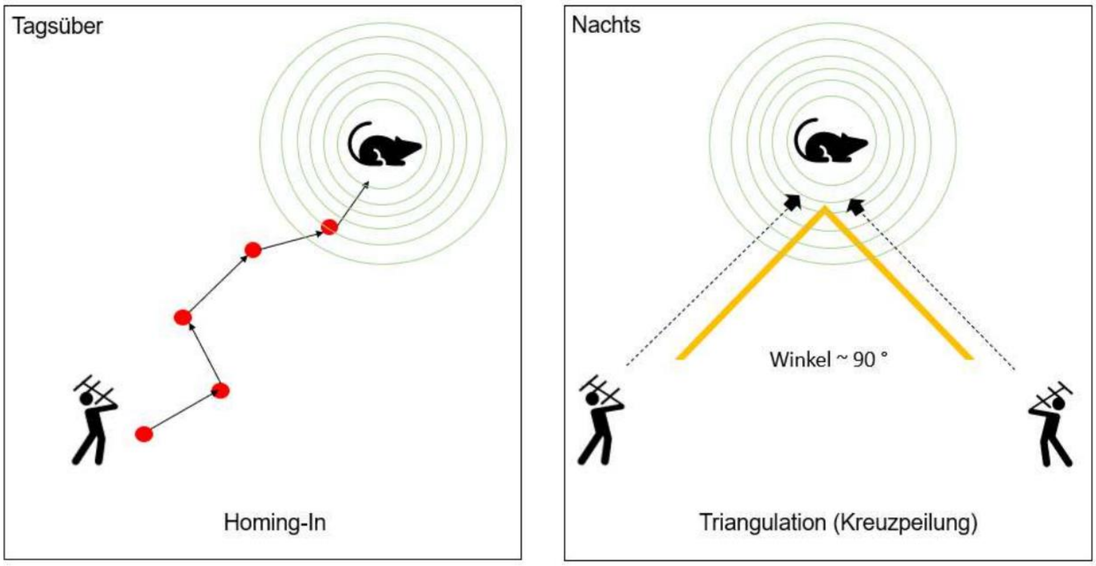

Figure 11: Simplified schematic representation of homing-in and triangulation. Created by Battermann (2022).

Telemetry used to be started when dusk fell during this study. The original plan was to start before sunset. Due to suspicious human activity in the area, we had to change our plans and could only start after dark. Positioning was stopped when the animal was no longer active at sunrise and remained in the same position.

2.5 Data analysis

2.5.1 Telemetry

Data processing

The data obtained from the nightly tracking had to be digitised for further processing. This was done by tabulating the handwritten data recorded in the field using Excel version 2301 (Microsoft Corporation, USA). Direct following meant that the data points - recorded with the GPS device - could be transferred directly to the computer without any further calculations. The data points were visualised using QGIS version 3.28.0 (QGIS.org 2023). No changes or corrections were made to the recorded GPS points. There were no noticeable inconsistencies in the visualisation of the points using QGIS. All telemetry points were included in the analysis.

Incremental area analysis

Incremental area analysis provides information on whether an animal's home range has been completely covered. The percentage increase in home range is calculated in relation to the number of detections. This gives an indication of how many detections were required to cover the entire home range of the individual. The results are presented graphically and interpreted on this basis. When the curve (i.e. the values) reaches a plateau, the entire home range of an animal is covered. This gives an indication of how many detections (absolute numbers) were required to cover the home range of the individual. An individual's home range is considered to be covered if 95% of the 100% minimum convex polygon is covered (Bertolino et al. 2003, Dreslik et al. 2003). Incremental area analysis is used to determine temporarily stable home ranges. This analysis, or graph, can also be used to see if a home range shift has occurred. Further analysis will only be performed on stable home range values.

Home ranges

Home range is generally understood to be the area where an individual carries out its species-specific and daily activities such as mating, foraging and rearing offspring (Burt 1943). Two of the standard home range calculation methods are:

01. Minimum convex polygon (Mohr 1947) and
02. Fixed Kernel Density Estimation (Worton 1989).

These two methods were used to calculate home ranges based on telemetry data.

The minimum convex polygon is a statistical method for calculating and displaying animal home ranges (e.g. from telemetry data). To create an MCP, points representing an animal's location are graphically displayed. A convex hull (as used in QGIS) is then placed over the outer edges of these points - in a straight line with the minimum distance from point to point. The MCP is the theoretical graphical equivalent of the animal's habitat. However, the MCP is susceptible to errors that can be made when recording locations. It is therefore important that the locations of the animals are not affected by disturbance. It may be that the person recording the data is shooing the animal, artificially increasing the home range. However, this may result in the MCP including larger areas with no actual use, as there is no density-based assessment of the frequency of the points (Worton 1995a, Mohr 1947).

Fixed Kernel Density Estimation (FKDE) is a non-parametric method for calculating the home range of an animal. Therefore, no assumptions are made about the underlying distribution. FKDE is used to observe trends in a data set. It is a probabilistic model that indicates the relative frequency of use of an area by the species of interest. It uses a utilisation distribution to calculate these probabilities. FKDE estimates the locations where the animal is likely to be found. In this thesis, the 95% and 65% kernels have been calculated. This represents the area of use which, in this case, contains 95% (home range) and 65% (core area) of the volume of the utilisation distribution. In other words, the lower the percentage of the calculation base, the more frequently used areas of the animal's home range are output. The concept is based on the fact that there are core areas within the home range that are visited more frequently (Kaufmann 1962). The smoothing operator chosen was the ad hoc method (href).

Home ranges are calculated using activity telemetry data. Daytime quarters could not be recorded as it was not possible to walk through the study area during the day. The Zoatrack website was used to calculate the MCP and FKDE. The website is used to process and visualise animal location data (Dwyer et al. 2015). The main feature of Zoatrack is that it simplifies data processing. The user is provided with an easy-to-use interface. Zoatrack uses the R (R Core Team 2022) package adehabitatHR (Calenge 2011) to perform the calculations.

Distances travelled

The maximum distance travelled per hour has been determined using only data separated by 1 hour to minimise autocorrelation (Rooney et al. 1998). An animal should be able to cross the MCP within one hour. This ensures that the area of activity has been fully recorded. It was calculated by using the minimum distance between consecutive fixes from Zoatrack. Since two fixes are not exactly 60 minutes apart, the data must first be calculated up to one hour or down to one hour:

$$\frac{Dist}{h} = \frac{Dist[m]}{\Delta t[min] * 60[min]}$$

$Dist$ represents the total distance travelled between two fixes and Δt represents time. However, these values are based on linear measurements of the distance between two locations and are therefore more theoretical. It is likely that the animal does not move in a straight line and that the actual distance is larger. The phrase "maximum distance moved" is derived from the data, as this value is the maximum that the data allows. This is therefore the maximum that could be measured, but it is not automatically the maximum that the animal moved. Only distances recorded during a single tracking session were used for the calculation, as in some cases there were several days between individual tracking sessions.

2.5.2 Habitat analysis

Only the Jacobs Index was calculated using both telemetry data and monitoring data. All other results based on monitoring data. Plotting and calculations were performed using RStudio (RStudio Team 2020) unless otherwise stated.

2.5.2.1 Habitat preferences – Jacobs Index

The Jacobs index is a method of determining whether a species has a preference for or an avoidance of a particular habitat-parameter (Jacobs 1974). Specifically, the use of a resource is related to the presence of that resource. The parameter studied in terms of use was vegetation zones - or rather structural units. These were classified based on impressions gained in the field, including a graphical evaluation in QGIS. The aim was to determine which habitat structures *M. roachi* prefers to use - or not. For this purpose, a rough classification into different habitat-classes was made (tab. 4). The calculations were done in Excel.

Table 4: Structural units recorded in 2022 in the study area north of Levka in south-eastern Bulgaria.

Structural unit
Sparse Forest
Forest
Open succession
Open succession, thick shrub
Open succession with few old oaks
Open succession with more old oaks
Field edge with grove
Pine plantation
Meadow
Thick shrub

As the area shows little variance, a more detailed classification of the structural units was not necessary as the areas were virtually identical.

The calculations used to obtain information on the preference and avoidance of certain parameters can be based on different databases. For instance, Jacobs index was calculated twice in this thesis using telemetry and monitoring data. For the telemetry data, the index was calculated for the MCP 100. The Jacobs index based on the monitoring data was calculated for the whole study area. The parameters (note: structural units) remained the same for both databases.

$$D = \frac{r - p}{r + p - 2rp}$$

$D = \mathit{Intensity\ of\ use}$
$r = \mathit{Proportion\ actually\ used}$
$p = \mathit{Proportion\ available}$

A result of 1 means total preference and a result of -1 means total avoidance.

2.5.2.2 Influence of habitat parameters

For the year 2022, it was investigated whether the habitat data collected in the field had an influence on the presence/absence of *M. roachi*. This was done by creating a binary occupancy matrix for the year 2022. For each sampling point, it was checked whether individuals of the species were detected there or not. The possible influence of these parameters on the catchability of a site was tested using binary logistic regression. A $p < 0.05$ indicates a significant effect. The data was recorded in two zones. Firstly, the number of shrub species, shrub stem density, number of wood species and wood stem density were recorded within one meter of a trap site or nest box. Within a 10 x 10 m transect around these sites, overstory tree distribution, overstory tree size, tree stump density, tree stump size and soil surface exposure were also recorded (see chapter 2.3.4).

2.5.3 Occupancy model

With both monitoring methods, the presence of the species can be detected when it is found in a trap or nest box. This is clear evidence of presence. Conversely, if the species is not detected by one of these methods, this does not mean that it is not present. The species may be present without being detected. Occupancy models are used to determine the probability of occupancy or detection. It is rather unlikely that a species will be detected perfectly. It is virtually impossible to detect the species with absolute precision every time it occurs in a place. Such models can indicate whether we are not detecting a species because it is not there, or whether we are not detecting it even though it is there. Occupancy models can indicate how likely it is that the species is present at a site, and what parameters influence this (Bailey et al. 2014, Royle & Dorazio 2008, MacKenzie et al. 2002, MacKenzie et al. 2006).

MacKenzie et al. (2002) developed a model to estimate the probability of occupancy of a site. It may be that the occupancy probability for a site is higher than the empirical data would suggest. Occupancy modelling is a relatively new discipline in ecology.

There are several ways to calculate such a model. One of them is the unmarked package (Fiske & Chandler 2011) in R that allows to calculate different models. The package offers several different functions, which in turn use or require different formulas and databases. In this thesis, the *occu()* function of the package was used. The *occu()* function calculates the MacKenzie et al. (2002) model. Multiple sampling of the same sites is required for this model. The *unmarkedFrameOccu* is based on zero-inflated binomial models (MacKenzie et al. 2006). The Occupancy state process (z_i) of an observed site i is calculated as (Fiske & Chandler 2011):

$$z_i \sim Bernoulli(\psi_i)$$

while the observation is calculated as

$$y_i | z_i \sim Bernoulli(p * z_i)$$

and

$$logit(p_i) = \alpha_0 + \alpha_1 * covariate$$

$$logit(\psi_i) = \beta_0 + \beta_1 * covariate$$

y_i = observation at site i

p_i = probability of detection at site i

z_i = true occupancy at site i

ψ_i = occupancy at site i

α = parameter to estimate detection probability

β = parameter to estimate occupancy probability

The model can take covariates into account. These correspond to certain site parameters that have been measured or recorded. They can be dynamic (changing from

visit to visit) or constant. Habitat structures recorded during the study period were used as covariates.
As a preliminary measure, presence/absence must be determined for each season (in this case: one season = one active season within a calendar year) and each sampling site. The databases are created in binary form, where 1 = detected and 0 = not detected. A sampling site in this case is a nest box or a trapping site. If the species was detected at a site in the year, a 1 is entered, otherwise a 0. Based on the occupancy patterns of the data matrix, the probability of occupancy and detection of a site can be calculated. First, a null model without covariates is calculated. Then models with covariates are calculated, i.e. a constant occupancy model and a constant detection model. The Akaike Information Criterion (AIC) of each model is then compared. The lower the AIC, the better the model fits the data from which it was calculated. The model with the lowest AIC is used for further analysis.

The covariates were recorded once in October 2022. Therefore, only those covariates that are assumed to have remained unchanged over the years could be included in the model. This only applies to woody stem density and number of woody species.

2.5.4 Population dynamics

2.5.4.1 Age Structure

To analyse the age structure, the number of marked juveniles (animals in their first year of life) and adults were counted for each year. Double counts were excluded. The data were transferred to RStudio as a data frame and plotted using the two packages ggplot2 (Wickham 2011) and reshape2 (Wickham 2007).

2.5.4.2 Weight comparison

The weights of a total of four sample groups were pooled and separately aggregated monthly for the years 2019 – 2022. A distinction was made between adults and juveniles and males and females. For adult males and females, the months of

- April,
- May,
- June,
- July,
- August,

and for juvenile males and females, the months

- July,
- August,
- September and
- October

were compared.

To illustrate the collected data, box plots were generated for each of the four groups. A Mann-Whitney U test was also applied to extracts from each independent sample dataset to determine if there were significant weight increases over the season. This was done by comparing the first dataset (e.g., April) with the last dataset (e.g., September), when these months contained sufficient data. The most distant months with at least n = 2 records were used for the test. To test whether there was a statistically significant difference in the weights of adult males and females, this was tested for one month with approximately the same n. Only juveniles that were independently moving and caught in traps were weighed. Juveniles in their nests were not weighed to avoid disturbance (Nedyalkov, pers. comm.).

2.5.4.3 Sex structure

Each individual of each sex was counted. As the animals are marked, double counts can be excluded. A Mann-Whitney U test was performed to calculate the deviation of the statistical groups. The counts for each year have been pooled.

2.5.4.4 Population size

The number of animals caught provides little reliable information on population size. Therefore, a suitable method for estimating population size is mark-recapture (Lettink & Armstrong 2003). Animals are either marked (e.g. by microchips, colouring, etc.) or can be individually distinguished (e.g. by morphological differences such as fur patterns). Based on these markings and distinctions between individuals, a variety of different population parameters can be calculated. These include the size of the population being studied (Lettink & Armstrong 2003).

A sample of the population is captured, marked and released. In further surveys, animals are then captured again and the proportion of marked animals and the proportion of unmarked individuals captured is determined. The recapture rates can then be used to estimate the size of the total population. One of the most basic models for this is the Lincoln-Petersen index. This model is used when the sample size is n = 2 (Chao 2001). However, the Lincoln-Petersen index assumes that the population is closed. This means that there is no immigration, emigration, births or deaths. It also assumes that there is a constant equal distribution and a constant recapture rate (Krebs 1999).

Another way of estimating the size of a population under study is the Jolly-Seber model (Jolly 1965, Seber 1965). There is a further development of this model called the POPAN model (Schwarz & Arnason 1996). To use the Jolly-Seber model, several criteria must be met:

01. homogeneous probability of survival
02. homogeneous probability of detection,
03. marking is retained,
04. samples are instantaneous snapshots, and
05. a constant study area.

The Jolly-Seber model is suitable for open populations, especially when the population is studied over time and births and deaths can be assumed. The POPAN-model uses the likelihood function. This makes it possible to estimate a hypothetical superpopulation (Schwarz & Arnason 1996). That model is particularly suitable for surveys under real conditions because it considers a certain dynamic in sampling. The POPAN model is based on three components: the probability of capturing an animal (p_i), the probability of an individual surviving the time between captures (φ_i), and the proportion of animals in the hypothetical superpopulation that enter the population after capture i and survive to time $i+1$ (b_i). An experiment with k observations is assumed. The two events, birth and death, are well defined. Thus, birth is the sum of all processes by which a capturable animal enters the population. This can be the actual birth of an animal, but also the fact that an animal enters the population by immigration. Death, on the other hand, includes all phenomena where an animal permanently leaves the population and can no longer be captured. Besides the actual death of an animal, this also includes leaving the population by emigration (Schwarz & Arnason 1996) (fig. 12).

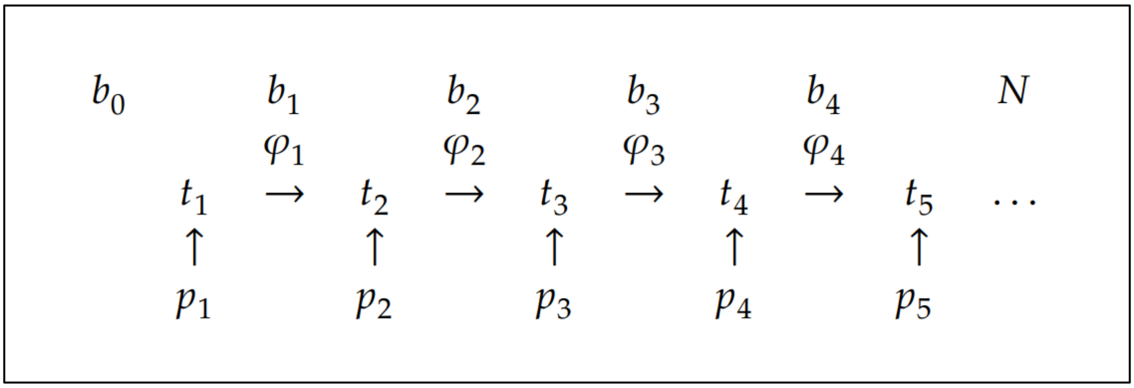

Figure 12: Basic mechanism behind the process model for POPAN parameterisation of Jolly-Seber experiments. p_i represents the probability of capture; φ_i represents the probability of survival; b_i represents the probability that an individual from the superpopulation N would enter the population; t_i.represents the time of capture. From (Schwarz & Arnason 2009).

B_i is the number of animals that emigrated after capture i and survived to capture $i + 1$, and B_0 is the number of animals alive before the first capture event. The sum of B_i is then the total population.

$$N = B_0 + B_1 + B_2 + \cdots + B_k - 1$$

This indicates the number of animals that have ever been in the population.
The total population calculated is based on the data 2019-2022. Each year was considered as one capture event. In reality, there were several capture events in one year, but some of them took place in different locations. Therefore, it was not possible to assume equal catchability at each sampling time. In addition, the sample sizes per sampling event were so small that they cannot be considered representative. To assume an almost identical probability of capture for all individuals in the study area, one season is considered a capture event. This means that there are a total of four capture events, each consisting of several sampling events. First, it was considered which individual was caught in which year, and on this basis a catch history was constructed. The number of individual catches of a single individual was irrelevant. The only relevant factor was whether or not the animal could be identified in that season. If this was the case, a '1' was recorded for that catch event. If not, a '0' was entered. This binary system results in a series of numbers. Since it is possible to track each animal individually through the

chip markings (and because of the low number of samples), it was possible to create an individual catch history for each animal and perform the calculation based on these results.

The calculation includes only records of animals that were of sufficient size to be microchipped (10 g) at the time of capture. The periods between the seasons were given with the same interval, as sampling starts at approximately the same time each year. Microsoft Excel (version 2303) was used to evaluate the individual catch history of each animal. The Jolly-Seber model was calculated using the two R packages marked (Laake et al. 2013) and RMark (Laake 2013). These packages can be used to select the model that best describes the values based on the AIC. This model is then used to calculate the population size. The results were plotted using ggplot2.

2.5.4.5 Mass comparison of nest material

The mean weight of the nests was calculated. The results were plotted using the ggplot2 package in RStudio.

2.5.5 Nest box compared to trap

To compare the two methods, the total number of animals caught in each of the years 2019 - 2021 was calculated for each year. As sampling in 2022 was different in some places in the study area, this year was omitted for this analysis. The aim was to test which of the two methods, nest box or trap, was better at capturing animals for examination. To make the two methods comparable, only data from juvenile (suitable size for microchipping) and adult, mobile animals were analysed. Litters with several young in the nest boxes were excluded. The analysis of the two methods was carried out to see which was better at capturing suitable animals for marking or further telemetry study. A permutation test using the R package coin (Hothorn et al. 2008) was used to test the sums of the two methods against each other.

3 Results

3.1 Success of catch for the telemetry study 2022

We captured a total of two individuals suitable for telemetry. One female (ID: M1) and one male (ID: M2) (tab. 5).

Table 5: *M. roachi* individuals selected for telemetry. They were captured during the study period north of the village of Levka in south-eastern Bulgaria. Both trapping and nest box methods were used.

Animal	Method of capture	Date of catch	Date collar applied	Total detections	Date first radio tracking	Date last radio tracking	Total nights
M1	Nest box	13.09	15.09	0	15.09	15.09	1
M2	Nest box	15.09	15.09	71	15.09	10.10	9

M1 could not be located even once because the radio collar failed. M2 could be radio tracked without restriction on nine nights from 15th September to 10th October. From 8th October to 10th October, M2 did not move at all. We therefore suspected that it had gone into hibernation. A week later, on 16th October, we were back at the site, but the tree hole was open and M2 had disappeared. We received distant signals but could not locate the individual. In 300 trapping nights, not a single *M. roachi* was caught. Catching success was only achieved by checking the nest boxes in the morning. A total of five additional individuals were captured but not of sufficient size for the study.

3.2 Incremental area analysis

Incremental area analysis can be used to determine whether the entire activity area of an animal was detected. It is also possible to determine how many detections were required to reach a stable home range. If this is the case, a plateau is formed at 100% of the area covered. This is the case for male M2 after 38 detections (fig. 13).

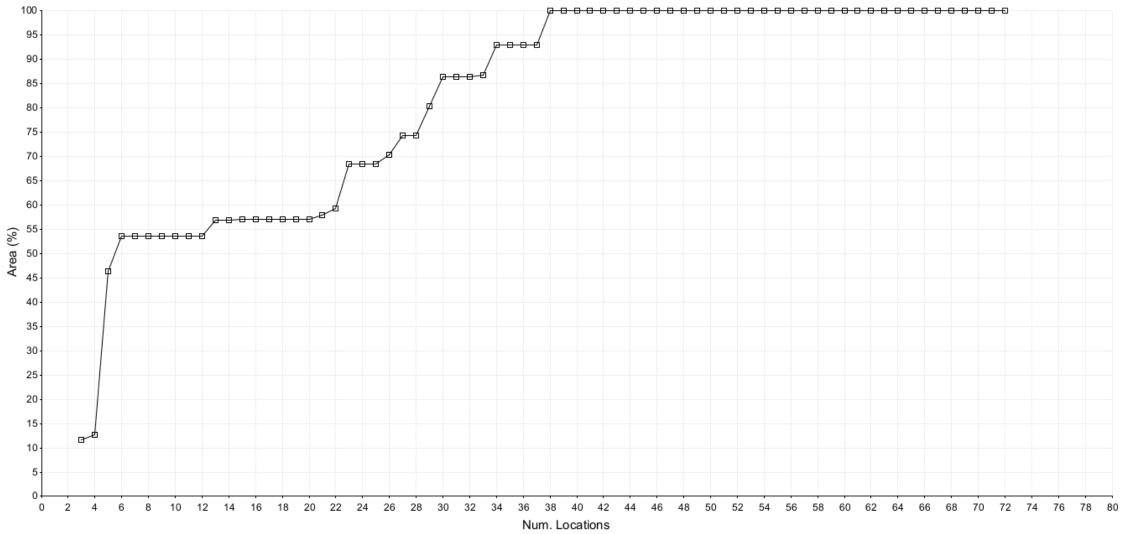

Figure 13: Incremental area analysis of the radio tracked male M2. The number of detections is plotted against the percentage size of the home range obtained. At 100%, the area covered by the MCP100 is shown.

3.3 Home range

3.3.1 Minimum convex polygon and kernel density estimation

Home ranges were calculated and represented using the minimum convex polygon and fixed kernel density estimation methods (fig. 14 & 15). The home range calculated for M2 using fixed kernel density estimation is larger than the MCP100. The K95 of 0.4524 ha is approximately twice as large as the MCP100 of 0.2252 ha (tab. 6).

Table 6: Home range analysis. Number of detections as well as MCP95, MCP100, K95, K65 in hectares.

Animal	Sex	Number of detections	Home range area [ha]			
			MCP100	MCP95	K95	K65
M1	Female	0	0.0	0.0	0.0	0.0
M2	Male	71	0.2252	0.1979	0.4524	0.1907

Figure 14: Home range of M2, represented as MCP 100 (top) and MCP 95 (bottom).

Figure 15: Home range of M2, represented as K95 (top) and K65 (bottom).

3.3.2 Distances travelled

M2 covered a maximum of 69.5% of his recorded MCP100 and 82.2% of his MCP95 in one hour. The longest distance M2 covered in one hour was 49.8m (tab. 7).

Table 7: Distance travelled by male M2 during the study period from September to October 2022. The maximum distances travelled within the MCP (95 and 100) are measurements taken from the most distant points.

Animal	Maximum distance per hour [m]	Minimum distance per hour [m]	Mean distance per hour [m]	Maximum distance travelled [m] within	
				MCP95	MCP100
M2	49.81	2.60	16.95	60,6	71,7

3.3.3 Daily resting sites

Due to certain local conditions, it was not possible to include the day quarters. As a result, these records are missing. However, on some nights, quarters (e.g. a tree hollow) were visited by M2 from 05:00 in the morning and were not left until the end of data collection at 07:00 in the morning. As we always started work around 21:00, M2 was already active. Therefore, it was not possible to determine whether any of the quarters visited in the morning were used throughout the day.

3.4 Habitat preferences

3.4.1 Jacobs Index

The study area was divided into 9 different zones (fig. 16). The two most common zones were sparse forest and open succession with thick shrubs (tab. 8). This was also the impression gained in the field.

Table 8: Structural units recorded in 2022 in the study area north of Levka in south-eastern Bulgaria. A rough classification of the units was made, as there was little variation in the field and the areas classified were virtually identical.

Structural unit	Occurrence (quantity)	Total size [m^2]
Sparse Forest	3	80,267
Forest	1	6,870
Open succession	1	1,707
Open succession, thick shrub	3	76,571
Open succession with few old oaks	2	26,756
Open succession with more old oaks	1	56,708
Field edge with grove	1	3,041
Pine plantation	1	12,851
Meadow	1	6,48
Thick shrub	1	6,997

In total, the areas zoned amounted to almost 280,000 square metres (appendix 2).

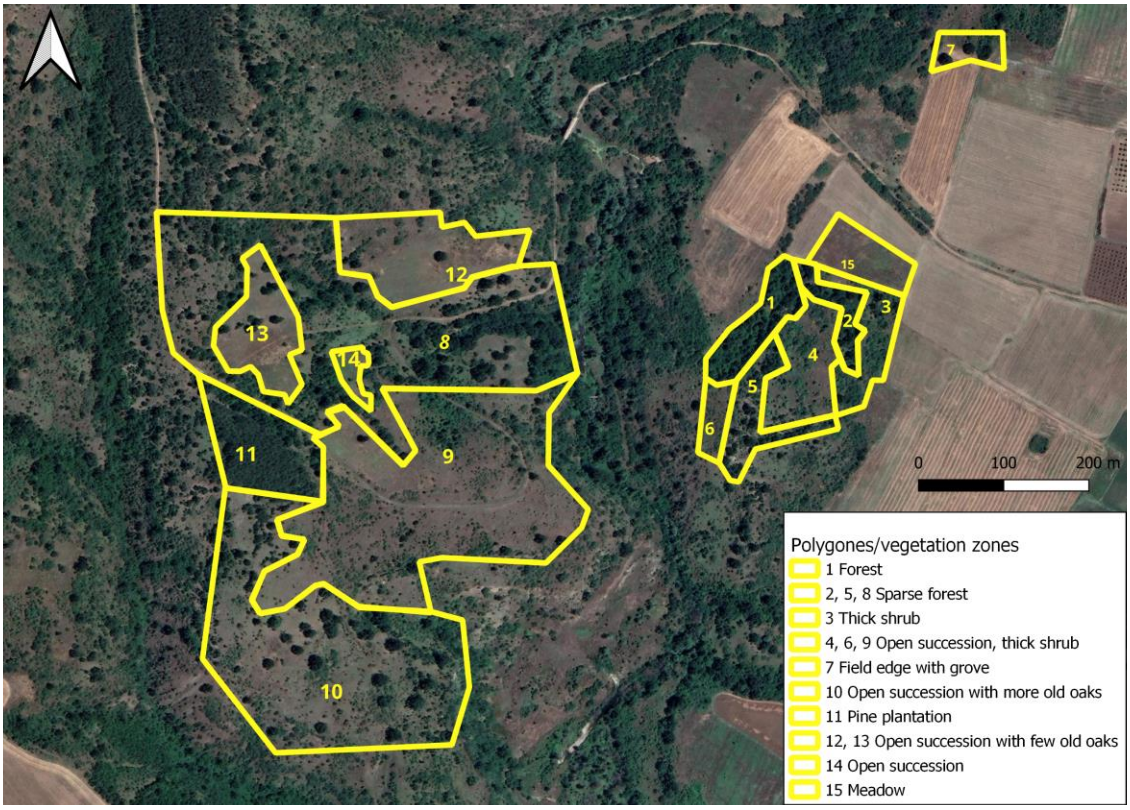

Figure 16: Polygons divided according to vegetation zone/structure type in the study area.

Area 15 (PG15) was never sampled during the monitoring programme. This area was only used to calculate the index from the telemetry data. It was not previously known that animals were present in these open areas. M2 spend most of its time in this area.

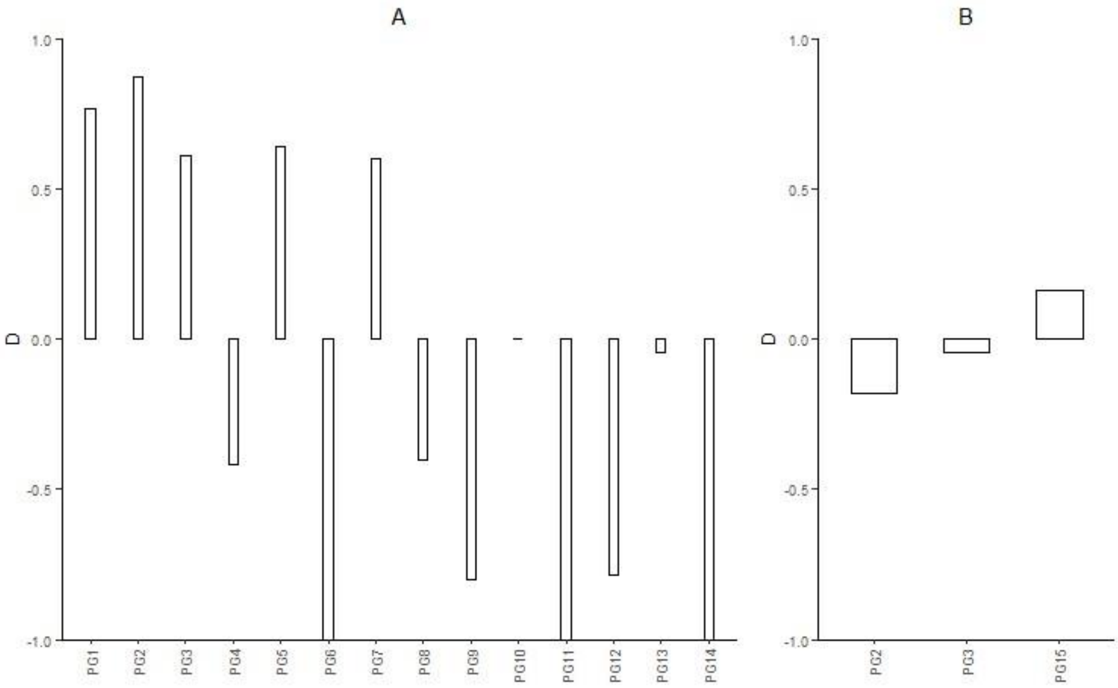

Figure 17: Result of Jacobs index based on long-term monitoring data (A) and telemetry data (B) of male M2.

Monitoring and telemetry data were analysed. The monitoring data cover a period of four years. The telemetry data is taken from the study period. Male M2 preferred to stay in the open area PG15 (fig. 17 B). Thus, a strong preference was expressed here. PG2 (sparse forest) and PG3 (thick shrub) were avoided by M2 (fig. 17 B). It is a common occurrence that M2 spent its activity phases in the open area PG15 throughout the study period. In direct comparison with the monitoring data, M2 seems to be an exception. Based on the results for the monitoring data, *M. roachi* seems to avoid open areas. The monitoring data show that wooded and densely bushy areas are preferred over open areas (fig. 17 A). The Jacobs index for the monitoring data shows areas PG2 and PG5, both classified as sparse forest, are both strongly preferred. PG2 is the most preferred of all sites. Open successions are generally avoided. Site PG7 is also preferred. The impression in the field showed that this site also appears to be shrubby. The area is located directly at the edge of a field and has old oaks as well as other woody plants (shrubs). According to the monitoring data, the sparse forest is the most preferred of all the areas. PG1 and PG3 were also preferred. These are classified as forest (PG1) and thick shrub (PG3). Again, *M. roachi* seems to avoid open terrain.

3.4.2 Influence of habitat parameters

The binary logistic regression showed that the parameters recorded in the field had no significant influence on the presence/absence of *M. roachi* (tab. 9). The lowest p-value is 0.0735 for soil exposure. However, even here the value is above the significance level of 0.05.

Table 9: Results of the binary logistic regression calculated with the glm() function in RStudio. A $p < 0.05$ indicates a significant influence of the variable.

Parameter	Estimate	Pr(>|z|)
Number of shrub species	-7.221e-01	0.3806
Shrub stem density	2.181e-03	0.9683
Number of woody species (NWS)	-1.320e+01	0.9956
Woody stem density (WSD)	-1.396e-01	0.6730
Overstory tree dispersion (OTD)	-3.037e-02	0.8295
Overstory tree size (OTS)	1.418e-02	0.4193
Tree stump density (TSDe)	7.603e-02	0.6339
Tree stump size (TSS)	4.562e-03	0.7808
Soil surface exposure (SSE)	8.460e-02	0.0735

The majority of the values are highly not significant with values $p > 0.7$. The estimates give an indication of the direction in which the occupancy of a site is influenced. If the estimates have a negative sign, it can be assumed that presence is negatively influenced.

3.5 Occupancy model

The first step was to look for covariates that were assumed to have remained unchanged over the period from 2019 to 2021. This was estimated to be true only for the number of trees in the transect and the number of tree species within the transect. Therefore, only these two covariates were included in the model.

First, a null model (OM0) was fitted assuming constant detection and occupancy. This model did not include covariates. A second constant detection model (OM1) was then fitted. This model assumes constant detection and variable occupancy as a function of the covariates. A third model (OM2) was fitted with the same covariates, but assuming constant occupancy and variable detection as a function of the covariates. OM0 had the lowest AIC and was therefore used (tab. 10).

Table 10: Comparison of the AICs for the three models. The model with the lowest AIC fitted the data best and was selected.

Model	AIC
OM0	276.705
OM1	279.7629
OM2	280.0402

If one model's AIC is within 2 of another, then both perform equally well on the data. This is the case for models OM1 and OM2 compared to each other, but not compared to OM0. Therefore, OM1 and OM2 are excluded from further consideration. The calculations were done using the MO0 model (fig. 18).

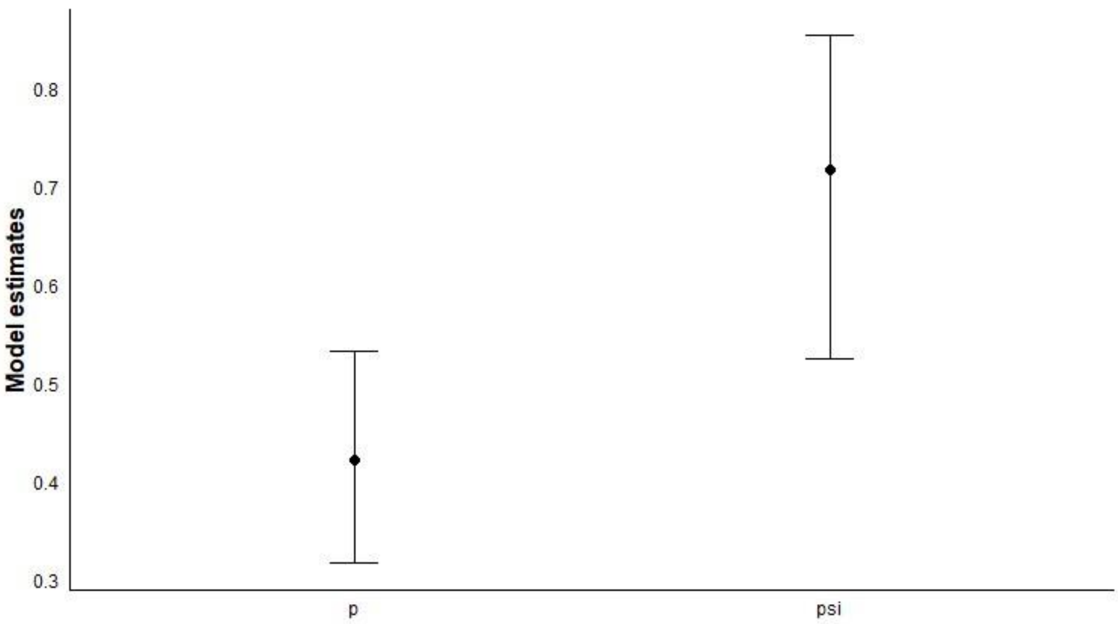

Figure 18: Result of the occupancy model. Shown are the estimates for detection (p) and occupancy (psi) and their 95% confidence intervals. The two points refer to the estimates calculated by the model. The two lines above the points represent the 95% confidence intervals.

The results are based on the model looking at detection patterns or non-detection patterns. The model gave an estimate for detection of p = 0.44. This corresponds to the probability of finding *M. roachi* if it actually occurs at that location.

The model gave an estimate for occupancy of psi = 0.718. This means that the animal is present at almost three quarters of all tested sites. The empirical sampling data over the years gave an occupancy of only 43.4% (sites where the species was detected at least once). The species was detected at 33 of the 76 sites. However, the estimate of the model indicates that the species is much more common than detected. The sampling data therefore underestimated the occupancy. The model increases the occupancy from less than half (43.4%) to almost three quarters (0.718).

3.6 Population structure

3.6.1 Age structure

After eliminating all duplicates of marked adults and juveniles, the number of individuals recorded was summed for each year (tab. 11).

Table 11: Absolute numbers of marked adults and juveniles of *M. roachi* recorded in the study area in south-eastern Bulgaria from 2019 to 2022.

Year	Adult	Juvenile
2019	7	16
2020	17	2
2021	11	49
2022	30	13

In 2019 and 2021, more marked juveniles were counted than marked adults. In 2019 they represented 70% of the recorded individuals and in 2021 82%. In 2020 and 2022, adults dominate. In both cases, if one group is dominant, that group makes up more than half of the recorded population (fig. 19).

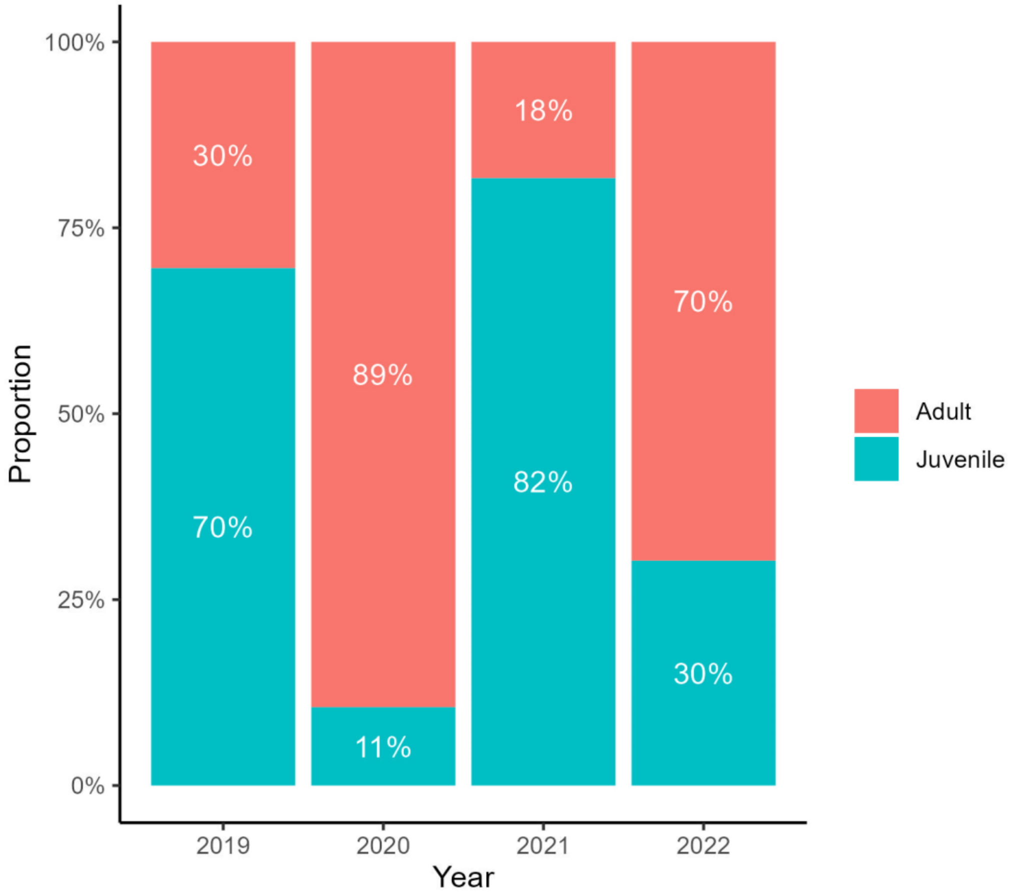

Figure 19: Age structure based on the absolute numbers of marked adults and juveniles of *M. roachi* recorded in the study area in south-eastern Bulgaria from 2019 to 2022.

Using the long-term monitoring data, the minimum age could be calculated based on the individual catch history of each individual. The oldest individual was at least four years old. Another individual was at least two years old. However, the majority of all catches were individuals caught in only one of the years. This was the case for almost 80 of the 111 individuals (fig. 20).

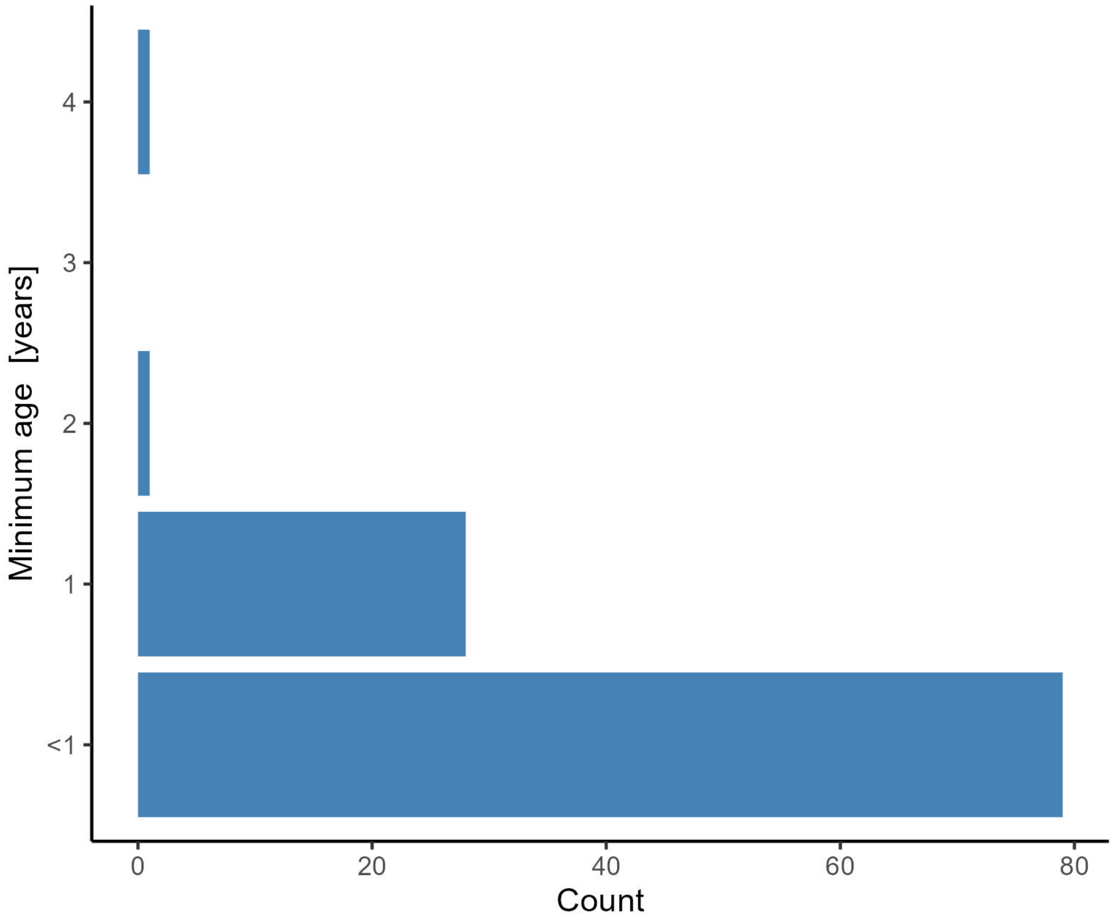

Figure 20: Minimum age structure based on capture-recapture data.

3.6.2 Weight comparison

Adults

Weight data were recorded for both males and females for the months of April, May, June, July and August (fig. 21). The heaviest male was recorded during July at 80 g, while the heaviest female was recorded during August at 65 g. The lightest male weighed 23 g and was recorded in May. The lightest female weighed 15 g and was recorded in July.

To test whether the weight differences of the males over the months was statistically significant, the data for April (n = 14) and July (n = 2) were compared as there was only one weighing in August. Due to the small number of observations (< 40), the exact p-value must be requested. The p-value of 0.03119 is below the significance level of 0.05. The null hypothesis is therefore rejected and there is a statistically significant difference between the two groups. On average, the males were statistically significantly heavier in July (75.5 g) than in April (34.5 g).

A comparison for females could be made for the months of May (n = 4) and July (n = 5), as there were too few data available in April and August with n = 1 observations. Due to the low total number of observations (< 40), the exact p-value must be requested. With a p-value of 0.9143, the test shows no statistically significant differences between the average weights in May (31.25 g) and July (35.17 g).

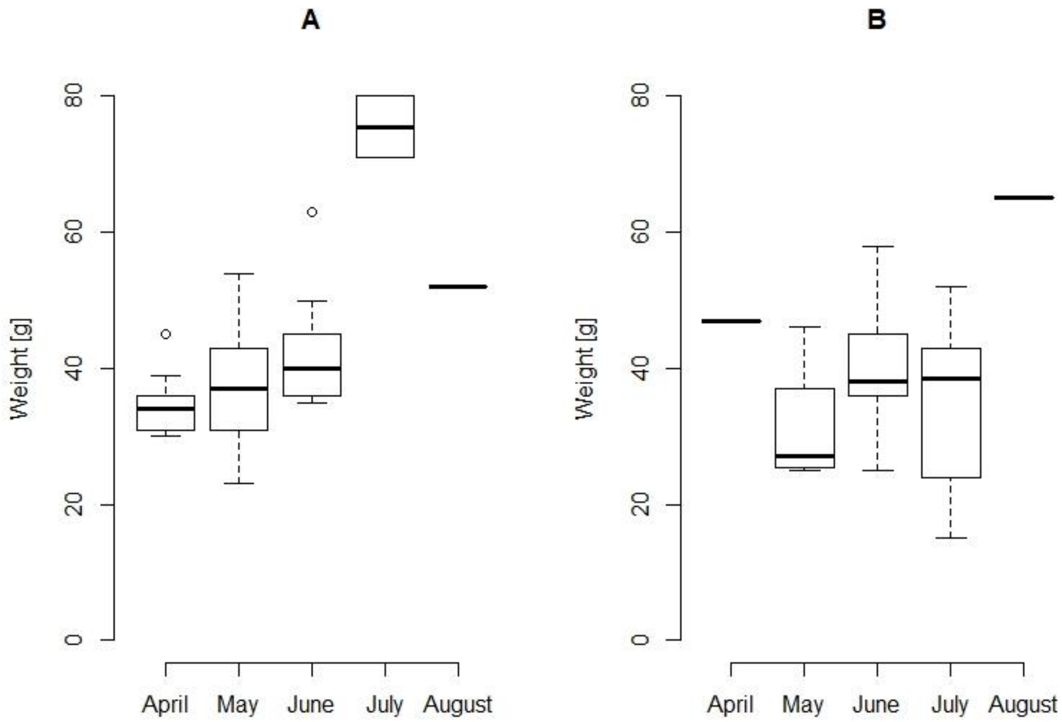

Figure 21: Box plot summarising the recorded weight data of adult male (A) and female (B) *M. roachi* over the period 2019-2022 in the respective recording months. Males n, corresponding to the plotted months 14, 17, 13, 2 and 1. Females n, corresponding to plotted months 1, 4, 10, 6 and 1.

To test if there was a statistically significant difference between the weights of adult males and females, a Mann-Whitney U test was also performed for a month with relatively similar n (males = 13; females = 10). The result showed that there was no statistically significant difference (p = 0.7089) between male and female adults in the month of June pooled over the years.

Juveniles

Weight data were recorded for both males and females for the months of July, August, September and October (fig. 22). The heaviest male was recorded during October at 60

g. The heaviest female was recorded during August and September at 43 g. Recorded in July, the lightest male weighed 16 g. The lightest female weighed 17 g and was also recorded in July.

The juveniles were also tested to see if there was a statistically significant weight increase over the recording months. For the males, the months of July (n = 17) and October (n = 5) were compared and tested. A p-value = 0.0009166 indicates a statistically significant difference between the two groups. On average, the males were statistically significantly heavier in October (51.2 g) than in July (19.88 g).

For the females, July (n = 18) and September (n = 2) were tested against each other. This resulted in a p-value = 0.02672. Thus, statistically significant weight differences between the two months can also be assumed for the juvenile females. On average, females weighed statistically significant more in September (36.5 g) than in July (21.01 g).

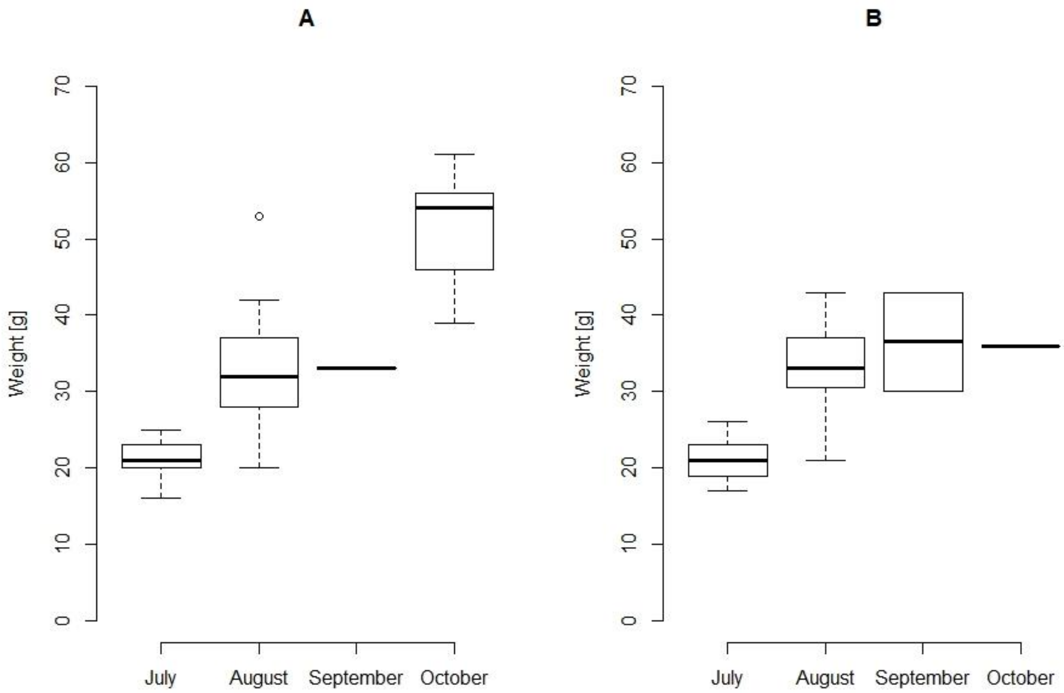

Figure 22: Box plot summarising the recorded weight data of juvenile male (A) and female (B) *M. roachi* over the period 2019-2022 in the respective recording months. Males n, corresponding to the plotted months 17, 26, 1 and 5. Females n, corresponding to plotted months 18, 19, 2 and 1.

3.6.3 Sex structure

Over the four years, the number of catches varied more for females than for males (fig. 23). In 2019, 13 males and 10 females were identified. In 2020, 12 males and 7 females were registered. In the following year, 2021, 29 males and 31 females were identified and recorded. In the last sampling year, 20 males and 23 females were identified.

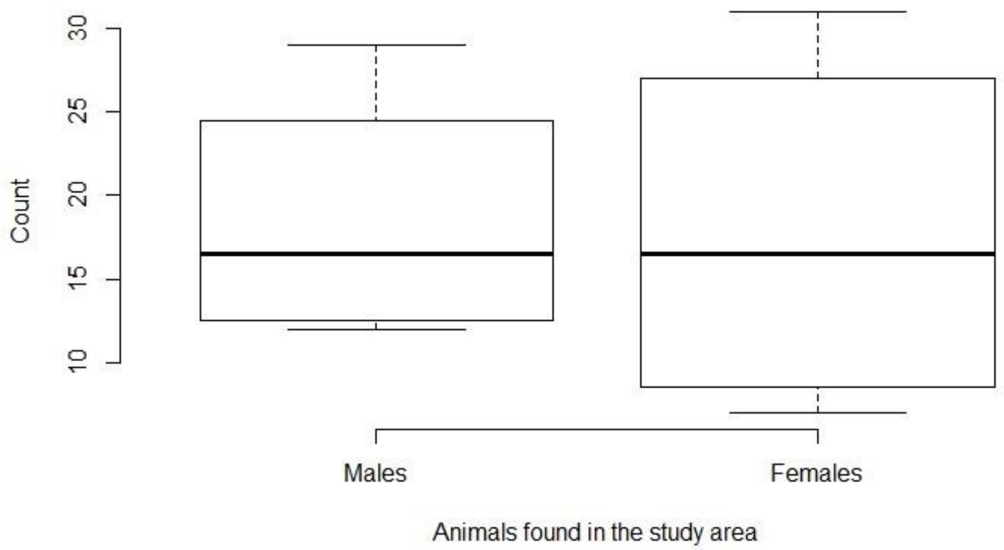

Figure 23: Boxplot of the total count of males and females over the years 2019 – 2022. A Mann-Whitney U test was performed ($p > 0.05$). The n for each year is as follows: 2019: 13 males and 10 females; 2020: 12 males and 7 females; 2021: 29 males and 31 females; 2022: 20 males and 23 females. Data were collected by checking nest boxes and trapping.

A Mann-Whitney-U test was performed on the means of the two groups. There are no significant differences between the means of the two groups. The p-value of 0.8852 indicates that there is insufficient evidence to reject the null hypothesis. The gender balance has been maintained throughout the monitoring period.

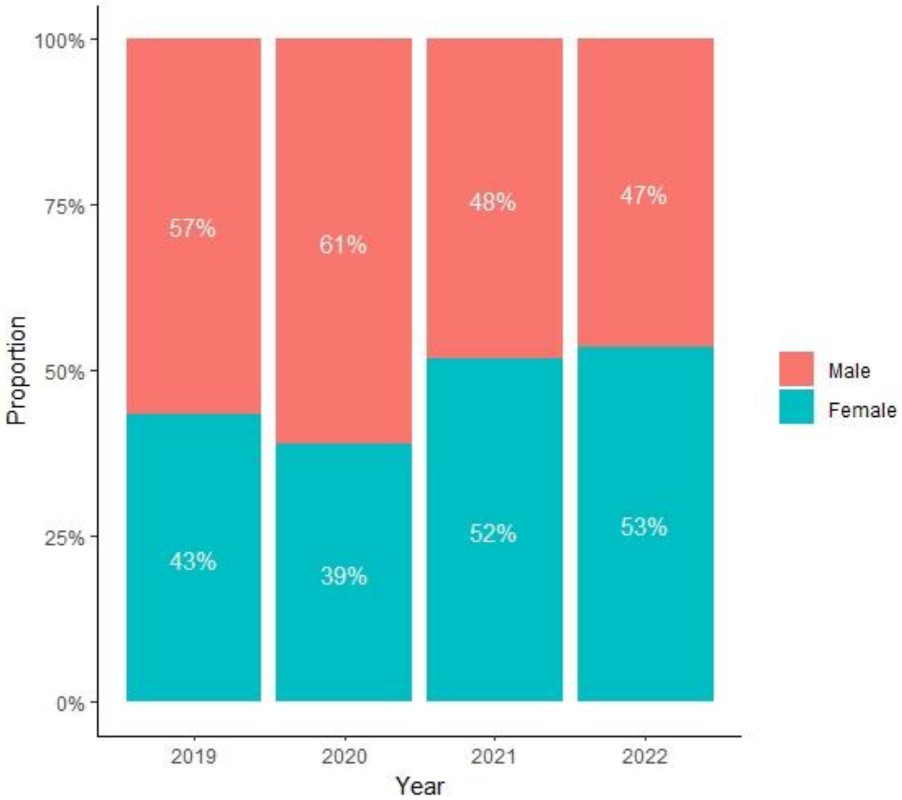

Figure 24: Relative proportions of males and females of *M. roachi* in the study area north of the village of Levka in south-eastern Bulgaria. The data were collected from 2019 to 2022. The n for each year is as follows: 2019: 13 males and 10 females; 2020: 12 males and 7 females; 2021: 29 males and 31 females; 2022: 20 males and 23 females. Data were collected by checking nest boxes and trapping.

In 2019 and 2020, there were more males than females relative to the total number of animals caught. In 2021 and 2022 the relative proportion of males and females was quite even (fig. 24).

3.6.4 Population size

The capture history of each animal was first considered individually (fig. 25). Based on this capture history, a numerical code (e.g., 0110; no capture, capture, capture, no capture) was then created for each animal to indicate whether the animal was captured in one of the years.

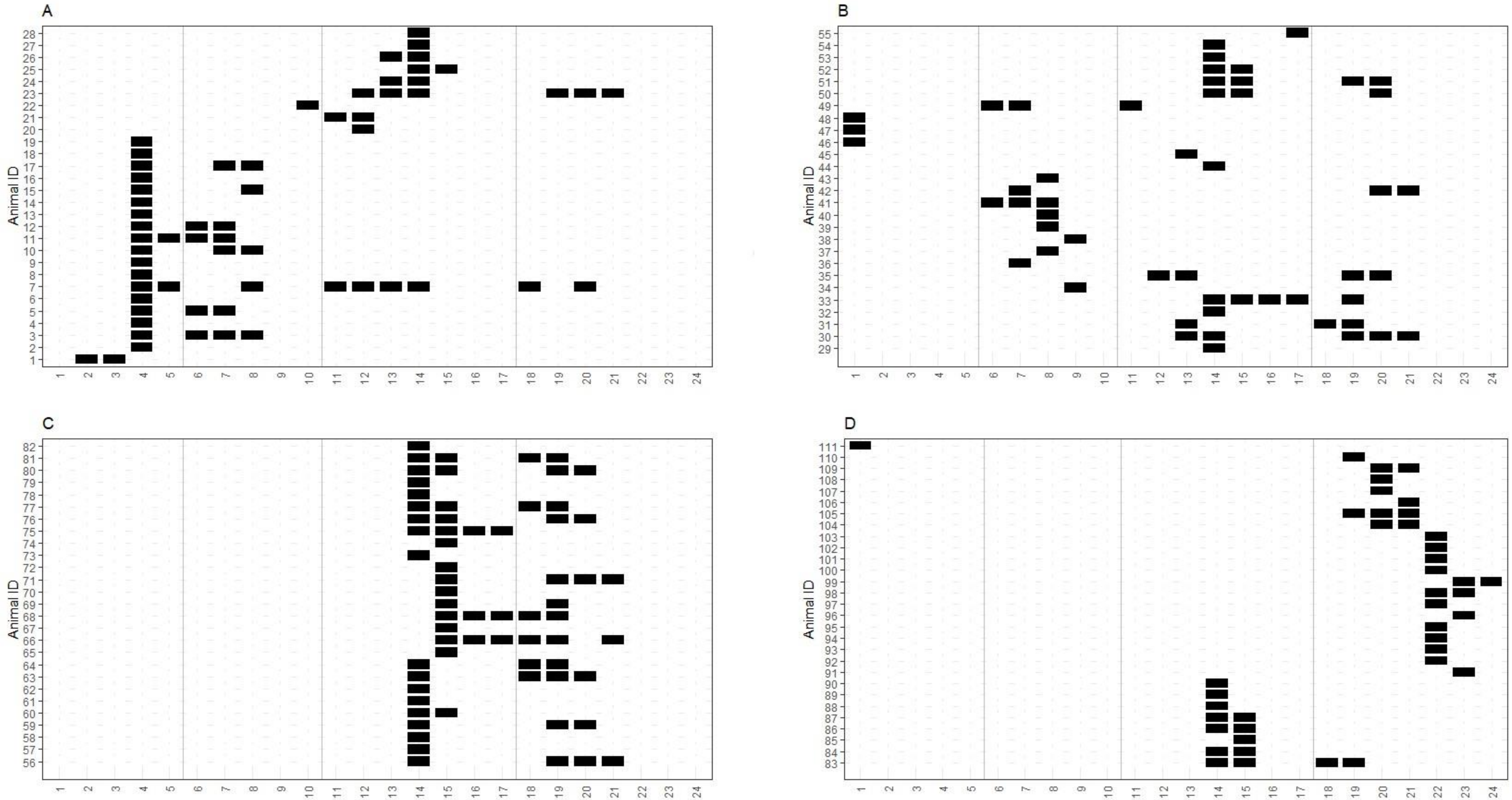

Figure 25: Individual catch history of *M. roachi* captured and tagged in the study area. A total of 111 individuals were captured and tagged during the years 2019 - 2022. Years are separated by vertical lines. The x-axis shows the number of all capture events since the start of the 2019 season. These individuals were subsequently released.

The population sizes were calculated using the two packages marked and RMark. Using marked it is possible to see which model fits the data best, as a tabular comparison of the AIC is easy to implement (tab. 13). In this case, model 4 was the best fit to the data with an AIC of 163.0315. Survival and entry probabilities are time-dependent, whereas detection and superpopulation are constant. This model can be used as the basis for further calculations. These model requirements can then be used for a calculation with RMark. Both packages use the POPAN parameterisation. However, individual values may differ slightly. RMark is particularly useful for calculating standard errors and confidence intervals.

Table 12: Console output in RStudio using the marked package. When ranking the AICs of each model, model 4 performs best. Further calculations are based on this model.

	Model	**AIC**	**ΔAIC**
4	Phi(~time)p(~1)pent(~time)N(~1)	163.0315	0.0000000
2	Phi(~1)p(~1)pent(~time)N(~1)	163.2053	0.1737779
1	Phi(~1)p(~1)pent(~1)N(~1)	197.7395	34.7079414
3	Phi(~time)p(~1)pent(~1)N(~1)	199.1317	36.1001834

The estimated population sizes (using both packages) differ only slightly in the decimals (tab. 14).

Table 13: Population estimates based on the two packages marked and RMark.

Occasion	marked	RMark
1	29.83855	29.83895
2	24.24438	24.24454
3	77.48438	77.48495
4	54.56401	54.56460

There are fluctuations in the estimated population sizes between capture events (years). The lowest population size was estimated to be 24 in 2020. The largest population was estimated to be 77 in 2021. Taking into account the 95% confidence intervals, the estimate for this year ranges from 23 to 131 (fig. 26).

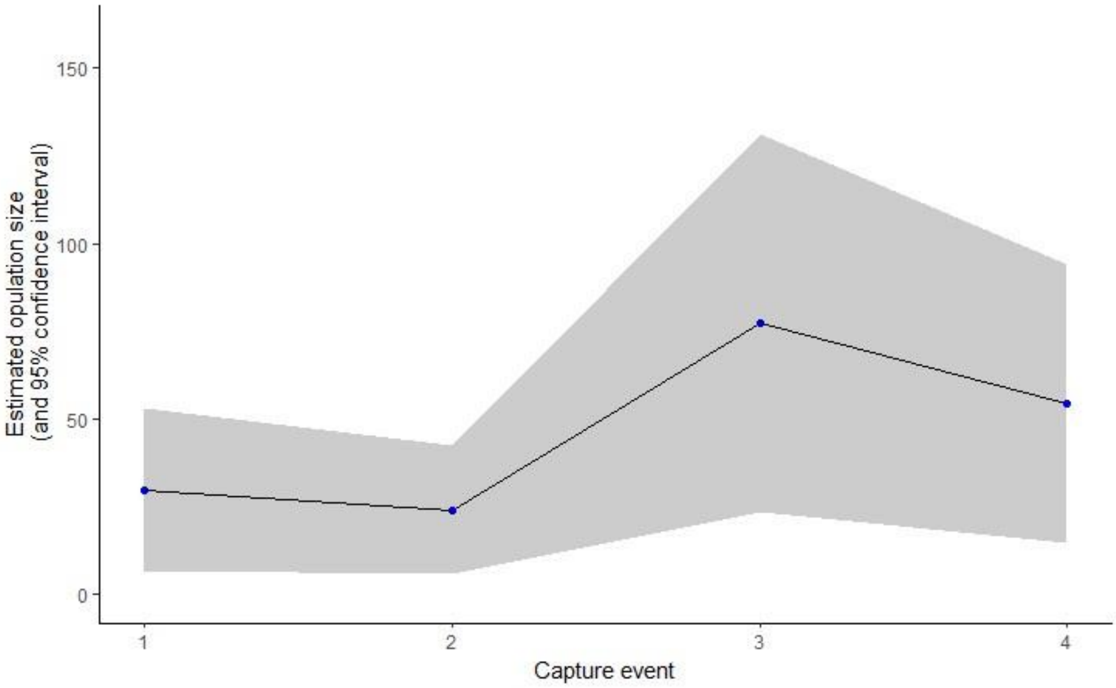

Figure 26: Population size estimates according to the two packages marked (black) and RMark (blue). As the calculated values are almost identical, the two lines overlap. To illustrate the results, additional points have been added to the graph based on the RMark results. The grey shaded area represents the 95% confidence intervals based on the RMark calculations.

Survival estimates between capture events according to the calculations with both packages are estimated to be 0.44, 0.17 and 0.48. The probability of detection is continuous and estimated to be 0.77. The probability of entry between events is estimated to be 0.09, 0.56 and 0.13. The estimated number of unmarked individuals in the superpopulation is 21. This results in a superpopulation of 132 (111 marked + 21 unmarked).

3.6.5 Mass comparison of nest material

In total, four nests were found and weighed during the check of 76 nest boxes. The lightest nest weighed 200 g, while the heaviest of the four nests weighed 460 grams. The average weight of the nests was 317.5 grams (fig. 27).

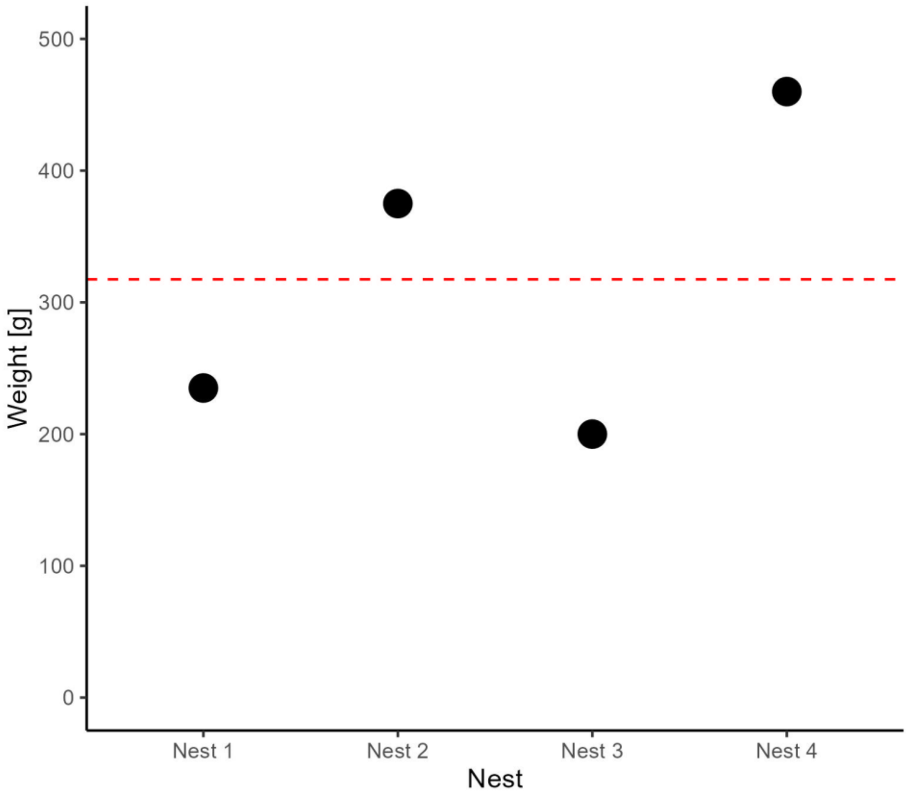

Figure 27: Weight of individual nests of *M. roachi* in the study area north of the village of Levka in south-eastern Bulgaria. A total of 76 nest boxes were checked and the nests inside removed for weighing. The red line shows the average weight of the nests weighed. The nests are sorted in the order they were found.

3.7 Nest box compared to trap

Data were first compiled for each method for each year. In 2019 and 2020 more animals were caught in traps. In the following year, 2021, more animals were found in nest boxes than were caught in traps (tab. 15).

Table 14: Catch history of the two methods 'nest box' and 'trap'.

Year	Nest box	Trap
2019	21	28
2020	23	34
2021	80	64
Sum	124	126

The result of the permutation test shows that there is no statistically significant difference ($p = 1$) between the two methods. Both methods show an increase in the number of animals in the years 2019 to 2021 (fig. 28).

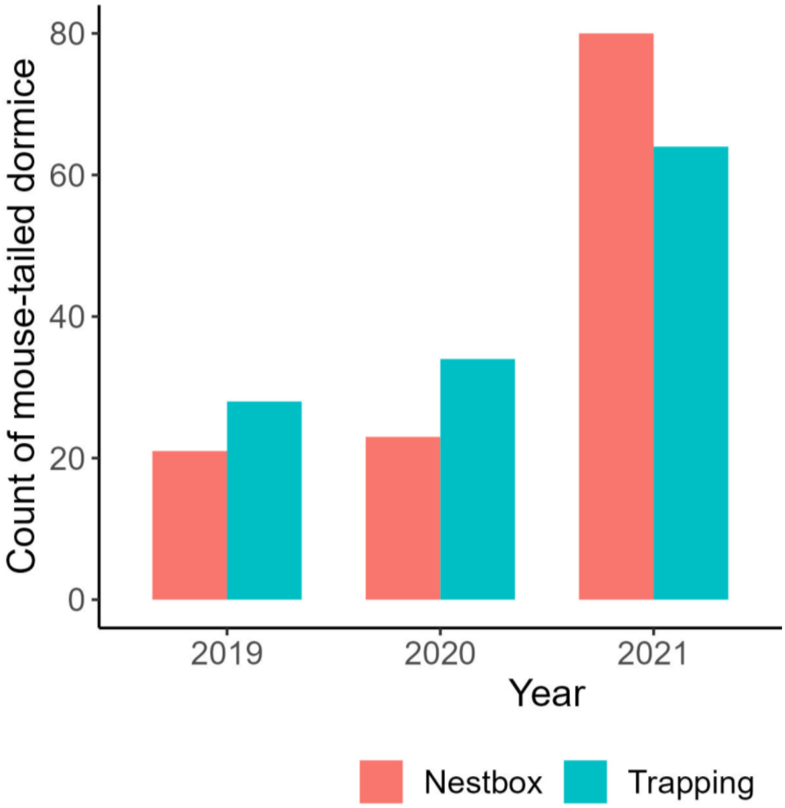

Figure 28: Catch history of the two methods 'nest box' and 'trap'.

4 Discussion

4.1 Methodology

4.1.1 Practical data collection methodology

Data basis

There are two parts to this work. One is the self-conducted telemetry and habitat description, and the other is the analysis of population structure and estimates of population size, as well as an occupancy model based on the long-term monitoring data. This work has also contributed to a part of the monitoring data for September and October 2022 by checking the nest boxes. However, the entire monitoring database used to calculate the occupancy model, population size estimates and population parameters includes the years 2019, 2020, 2021 and 2022. As there has never been a radio-collaring study on this species, only the data from this study can be used for interpretation.

Study area

The study area was defined by Dr. Nedyalkov after the new discovery of *M. roachi*. Accordingly, the study area of this work is based on this definition. The study area consists of two parts. A more or less flat front part and a hilly rear part. The flat part is more accessible and is located near a dirt road and is therefore easier to reach. To get to the back part, a walk of about 15-20 minutes must be planned. It was therefore decided to use only the front part of the study area for telemetry. The simple reason for this was that it would have been impossible to track several individuals within an hour due to the distances involved. However, nest boxes in the rear part of the study area were checked and animals recorded in the monitoring database.

Time period and animal activity

The time period for this study was chosen to cover the end of the season. One aim of this work was to find hibernation sites. Adults can sometimes go into hibernation as early as the end of September, while juveniles take a little longer to reach the required weight and can therefore be active until the end of October and into November (Nedyalkov, pers. comm.).

During the period of telemetry used in this study, juveniles born in the same year are already large enough to be radio tracked and are preparing for hibernation. This increases the number of animals available for telemetry compared to spring, as females are no longer lactating and active on their own. Possible age- and sex-specific peculiarities in seasonal behaviour could therefore lead to over- or under-representation of certain population groups. This could be better classified if telemetry was carried out over an entire season or if telemetry studies were available for the different periods of the season. It can be assumed that females in spring show a very different behaviour towards the end of the season when they are preparing for hibernation alone. For example, *Glis glis* is likely to reduce its home range in autumn in response to the increased number of young (Hönel 1991). However, this behaviour has not been observed for *Eliomys quercinus* (Vaterlaus 1998). In order to demonstrate this for *M. roachi*, comparable data would have to be collected over an entire season. This is simply not possible within the scope of this thesis.

Capturing animals

A distinction must be made between the two methods of trapping and nest box checking. The sole purpose of trapping is to capture animals. As in the case of *M. roachi*, the animals are caught during their active phase. Bait is usually placed in the traps to increase the attractiveness. The choice of bait has an enormous influence on the success of the catch (Gurnell 1980, Beer 1964, Harkins et al. 2019, Woodman et al. 1996). It is sometimes possible that bait acceptance varies with the season (Fitch 1954). The choice of trap may also have an influence on catch success, as traps may be perceived differently by different species (Sealander & James 1958).

Nest boxes are more versatile than live traps. It must be said that nest boxes are often used as retreats. In this respect, unlike traps, it is not evidence of an active animal, but rather confirmation that the nest box has been used as a resting place. However, nest boxes can also be used as a detection or trapping method. The difference with overnight trapping is that nest boxes are checked during the day for nocturnal animals. For *Muscardinus avellanarius*, nest box checking has been shown to be a highly effective detection method (Büchner 2016). However, *Eliomys quercinus* can also often be found in nest boxes (Straub 2021). Our own inspection of nest boxes in the study area showed that *Glis glis* and *Dryomys nitedula* also like to rest in nest boxes. For *M. avellanarius* it has also been shown that nests are often built in nest boxes for rearing young (Odreitz 2014). However, nest boxes also have advantages that should not be underestimated, apart from the method of nesting itself. Nest boxes have been shown to have positive effects on small mammals by providing important refuges (Goldingay et al. 2015, Goldingay et al. 2018, Luna et al. 2020, Juškaitis 2006). Especially in young forests,

where old trees with cavities, cracks, etc. are missing, they are accepted more often than in old forests (Lindenmayer et al. 2009). Juškaitis (2006, 2008) found that a high density of nest boxes can quadruple the number of *M. avellanarius*.
These two methods proved to be suitable for detection and capture. However, in a mark-recapture study it is very difficult to capture all individuals. This is mainly due to the detection probability of the species, which can vary greatly. Catchability in reality is therefore rather uneven (Jolly & Dickson 1983). The location of a trap or nest box is also very important. In some places in the study area, animals could never be detected, but about 30 metres away they are regularly found (Nedylakov, pers. comm.). Occupancy by other species is also important, as baits attract not only the target species but also other species. For example, a trap will be occupied and no longer accessible to *M. roachi* (Nedyalkov, pers. comm.). The time of sampling is also crucial, as the activity of a particular demographic group shifts during the season. For example, juveniles that are usually born at the end of June won't be detected (in this case, caught in a trap) until July/August (Nedyalkov et al. 2022). Adults, on the other hand, tend to go into hibernation earlier and are harder to detect in late autumn (Nedyalkov, pers. comm.).

The practical data collection for the population structure is done through nest boxes and trapping. The animals are then entered into the database as described in the handling of animal's section, or a record is made of the recapture, and individual animals are weighed. Analysis of sex structure or age composition is particularly valuable when these data are collected over a long period (Clutton-Brock & Sheldon 2010).

Animal handling

Detecting an individual is not sufficient to include it in the database or collect it for telemetry. Proper handling of the animals is essential. An animal might escape before it can be weighed, microchipped or collected. In this case, a record may be made in the database that an individual has been seen, but this record does not provide any evaluable data. Important metrics such as weight cannot be recorded in this way. It is also not possible to record whether the animal has been marked or not. Data might be recorded incorrectly. Incorrect weights due to wind or strong movements of the animals can be largely avoided, but not completely eliminated. Incorrect sex determination can be made if the sexual characteristics are not particularly developed. However, it is very possible to record the relevant characteristics. The use of plastic bags for weighing and preparing animals for handling proved effective. Isoflurane proved to be an effective anaesthetic. Given the short duration of anaesthesia, quick but precise work is essential.

Applying the collars proved to be tedious as the equipment was small and had to be applied with great precision. It is advisable to plan each step carefully.

Telemetry

Radio tracking of animals is a widely used method for determining and providing the basis for calculating home ranges. Radio tracking is primarily a cost-effective method for studying various parameters such as movement, resource selection, physiology or population demography (Millspaugh & Marzluff 2001). The Holohil transmitters proved to be reliable and easy to locate. Homing-in made it possible to determine the exact position of an animal. This was achieved by continuous approach combined with directional limitation based on the gain. A distinction was made between active and passive tracking based on habitat use. If the animal could be located in open space, it was always an active tracking. At the edge of the forest, it was first necessary to check whether the animal was moving in the bushes on the ground or whether it was retreating into a tree hollow. This was also done by carefully approaching and identifying the position. If the animal was moving, the signal would change. We avoided disturbing the animal by approaching very quietly and carefully. In order for the data to be useful for home range calculations, autocorrelation, i.e. the independence of the tracking data, must be avoided or minimised. One drawback was the battery life of the transmitter. This was less than the manufacturer stated. According to the manufacturer it was 40 days. In our case the battery lasted 25 days. Female M1 could not be tracked at all, as no signal was emitted from this transmitter. It is suspected that the transmitter's antenna was positioned in such a way that M1 was able to bite it. The homing-in method proved to be reliable and efficient. Previous training with the equipment to estimate distances and directions meant that precise localisation was possible using only one antenna and receiver. The five additional individuals that had been caught were either not heavy enough for the radio collar or too far away from M1 and M2, so it would not have been logistically possible to radio track all. Although the amount of data from telemetry was less than planned, it can be considered a success.

Habitat parameters

Recording the data proved to be laborious, as values such as shrub density or soil exposure were partly based on estimates. However, the fact that the data was collected by two people at the same time improved the quality of the data. The choice of parameter categorisation proved to be helpful and well suited to the prevailing conditions. Selecting the individual parameters as well as the perpendicular transects can also be described as successful.

4.1.2 Data analysis methodology

Telemetry

For the calculation of the home range, it is recommended to use more than one method (Harris et al. 1990). Therefore, two of the standard methods were used for the calculation. The MCP method ensured a better literature comparison, as this method is used in most publications on dormice (Vaterlaus-Schlegel 1997, Bertolino et al. 2003; Juškaitis 2005, Ściński & Borowski 2008). The Garden dormouse (*E. quercinus*) in particular has been radio tracked very intensively in recent years - especially in Germany and Italy - and therefore provides good comparisons. According to the literature, more reliable home ranges can be calculated using the kernel density estimation method (Börger et al. 2006). Vaterlaus-Schlegel (1997) states that the MCP method can overestimate the home range of an animal. As kernel density is the more reliable method for estimating home ranges, fixed kernel analyses (Worton 1995b) were also carried out. An insufficient number of data (samples) can lead to an over- or underestimation of the home range for both methods used (Harris et al. 1990, Kenward 2001). To avoid this, it is recommended to record at least 30, but to be on the safe side at least 50, sites per individual (Seaman et al. 1999). Incremental area analysis can then show if and when an animal's entire home range has been covered. It should be noted, however, that these home ranges are only temporarily stable. It is not uncommon for them to change over the course of a year. Using Zoatrack greatly simplifies the working wall. Otherwise, the functions would have to be calculated individually with R. However, the output of the home range sizes on the homepage itself is rather inaccurate regarding the area sizes. Therefore, the home ranges were recalculated using QGIS.

The distance travelled was calculated from Zoatrack output. Using only data recorded at least 1 hour apart minimises autocorrelation (Rooney et al. 1998). Hourly tracking data are reasonably independent of each other. The distance travelled by an animal in an hour is a good way of demonstrating that the area of activity has been covered. The animal must be able to cover the distance of the MCP100 in approximately one hour. Autocorrelation of the data can be caused by the animal itself if it stays in the same place for a long time (Michler 2003).

Daytime quarters could not be recorded as it was not possible to enter the study area during the day. Therefore, only night-time data are available.

Habitat analysis

The Jacobs index provides information on the preferences for a particular parameter. In the case of this thesis, this parameter is habitat type. The Jacobs index is a useful method when the number of animals studied is too small for compositional analysis (Jacobs 1974). However, it has not been clearly demonstrated whether an increased use of a category actually means a preference or rather an avoidance of certain other habitat structures (Aebischer et al. 1993). A detailed classification of the habitats in the study area would probably have provided better information on preferences or avoidance. However, this was not possible due to the size of the area and the time available. It should be noted that the evaluation of the telemetry data assessed supply vs. use (of the habitat zones) in the determined home range of M2. The evaluation of the monitoring data does not include home ranges, but rather data from the entire study area.

Binary logistic regression was used to determine the possible influences of the parameters collected in the field around the nest box and trap locations. Many of these parameters were not applicable to the available data from 2019 to 2021, because, for example, shrub density or the number of shrub species could have changed significantly during this period. Regressions are an unthinkable cornerstone in statistical ecology regarding habitat influences (Nad’o & Kaňuch 2018, Morris 1987, Yu & Lee 2002, Pereira & Itami 1991, Mladenoff et al. 1999).

Occupancy Model

The R package unmarked is probably the best-known package to calculate occupancy models. Overall, occupancy models are still a relatively young discipline in statistical ecology and their development really took off in the early 2000s (Bailey et al. 2014). Species abundance and its dynamic components, extinction and colonisation, are key parameters for ecological studies (Royle & Kéry 2007). Only the two covariates 'woody stem density and 'number of woody species', which were classified as invariant in the years 2019 - 2021, were included from the recorded field parameters.

Population dynamics

As only the data of marked animals were used for the calculations, errors can be largely excluded. In particular, multiple counting or weighing of the same animal within one month.

The POPAN parameterisation of the Jolly-Seber model is one of many approaches to the statistical estimation of population size. Schwarz and Arnason (1996) parameterised the Jolly-Seber model to additionally estimate a superpopulation and the probability of an individual entering that population. This parametrisation is therefore a further development of the model. A limitation of the POPAN method are parameters that cannot be calculated separately. These include, for example, the first probability of occurrence and capture or the last probability of survival and capture. In addition, the POPAN parametrisation is not very robust to fluctuations in catching probability (Kendall & Pollock 1992). The POPAN model can be used to produce two abundance estimates. One is the estimated population size at each capture event and the other is the superpopulation, which represents all individuals that could not be captured. As the data used for the model in this thesis are annual, the output of the survival probability is of particular interest. From this value it is possible to deduce how many individuals will survive the winter. This classification from year to year had to be done because the sample sizes per individual capture event would have been too small. In addition, sampling was selective and not at every potential location of every individual at every sampling time. A season was counted as one capture event in order to create an almost identical catchability of the animals The two packages RMark and marked were used for this calculation. This was done because both packages have a slightly different approach. On the one hand, the population size was estimated "by hand" using the marked package and the function popan.derived of the RMark package. In principle, "by hand" just means that the estimates are calculated using a predict function, whereas RMark has already implemented this possibility as a package-specific function. This should serve to compare the two packages on the one hand, and to see if the results differ from each other on the other.

Nest box compared to trap

Irrespective of the added value of nest boxes, it was important to check which method provided the greater overall catch. To do this, the total catches of each method were summarised and compared. This should be done mainly in the context of monitoring and telemetry to determine which method is more efficient to capture animals.

4.2 Result discussion

The first description of this species was made in 1937 by Bate as *Philistomys roachi* and was based on fossils. When it was first discovered in Bulgaria in the late 1950s, it was thought to be *M. personatus*. It is only since the 1950s that this species has been known to exist. Rossolimo (1976) recognised that the animals from Bulgaria were a separate species and described them as *M. bulgaricus*. Corbet & Morris (1967) suggested that *P. roachi* was a new synonym for *M. personatus*. After changes in the nomenclature or classification of the species over the years, the name *Myomimus roachi* was finally agreed upon. The species has a very limited range and ecological data on the species are scarce. Notwithstanding the need for biological research, it is particularly important to look after this species as it is also protected at European level. If an effective conservation programme is to be put in place, sufficient basic knowledge needs to be built up. As this species was thought to be extinct, it is particularly exciting that we have had the opportunity to radio track and monitor this species for the first time.

As this species has not been radio tracked before, the results can only be compared with other dormice species, and firstly it should be noted that results from one tracked individual are of limited significance. It is not certain that the data collected by telemetry can be applied to other individuals, age classes, females or to mouse-tailed dormice in different habitats. Nevertheless, the data offer insights that were not previously considered relevant. In general, the basic data on *M. roachi* is very scarce and can rarely be compared with the results of other researchers on this species. Although two animals were captured for telemetry, only one could be radio tracked successfully. This is particularly unfortunate as the other individual was a female. This would have provided data for at least one individual of each sex. However, according to Seaman et al. (1999) there are sufficient locations for male M2. Therefore, it can be assumed that the home range could be estimated accurately.

For the first time, we were able to document the home range of *M. roachi*. We have been able to show how large the home range of a male representative of this species is in preparation for hibernation. The home range of M2 is rather small compared to the MCP100 of *M. avellanarius* (0.25 - 2.5 ha) or *G. glis* (0.5 - 11.2 ha) (Müller-Stieß & Vaterlaus 1995). However, the recorded home range of M2 is still close to the smallest home ranges of *M. avellanarius*. Studies on *E. quercinus* have shown that the home range of males is generally larger than that of females (Bertolino et al. 2003, Diederichs

1999, Vaterlaus 1998). Also, for *M. avellanarius*, Bright & Morris (1991) found that the home ranges of males were larger than those of females in Somerset, UK. However, the time of data recording is also an important factor. Vaterlaus (1998) found that males had larger home ranges during the rut for *E. quercinus*. Hönel (1991) could also demonstrate this phenomenon for *G. glis*, with the difference that lactating females occupy a smaller home range as they take care of their litter. In addition, it was shown that the animals reduce their home range in autumn in response to the increased number of individuals due to the young (Hönel 1991). Hönel (1991) and Vaterlaus (1998) have also shown that females increase their home range to find nesting and feeding sites. Bertolino et al. (1997) found that for *E. quercinus*, non-gestating females can have a larger home range than gestating females due to their higher mobility. As there is no information on home ranges for *M. roachi*, this can only be speculated.

M2 covered an average distance of 16.9 m/h. The use of space does not only include the home range. The distance covered in a given period of time is also part of spatial use (Vaterlaus 1998). Wuttke (2022) and Battermann (2022) found that two male *E. quercinus* in the Harz Mountains in Germany covered an average of 17.23 m and 21.44 m per hour. *G. glis* is known to cover many hundreds of metres in one night (Morris & Hoodless 1992, Jurczyszyn 2006). *M. avellanarius* can also cover several hundred metres in one night (Bright & Morris 1991). In the Harz Mountains, a male *E. quercinus* was found to cover more than 1200 metres in one night, climbing 200 metres in the process (Diederichs & Stubbe 2003). Vaterlaus (1998) was able to demonstrate that *E. quercinus* can cover similar distances in the Alps. To put the distances travelled by M2 in this study into a species context, more animals would need to be radio tracked.

M2 showed site fidelity during the telemetry study. This observation is consistent with what is known about other dormouse species (Vietinghoff-Riesch 1952, Schlund et al. 1993, Diederichs und Stubbe 2003). In other studies in Bulgaria, *M. roachi* was caught mainly on the ground (Peshev et al. 1960), whereas Kurtonur & Özkan (1990) caught it mainly on trees. Nedyalkov et al. (2018) found that *M. roachi* spends most of its time on trees. In this study, we were able to show the opposite, with M2 spending most of its time in an open area, on the ground. The grass in this area was about knee high, but not very dense. It is likely that M2 would have found much more cover in the adjacent forest than in the open area. This is interesting because many forest animals have a strong fear of open areas (Vaterlaus 1998). Open areas or paths are often insurmountable obstacles for small mammals. M2's behaviour suggested the opposite. Roads, for example, can be an insurmountable barrier for some animals (Rico et al. 2007). Kozakiewicz & Jurasińska (1989) found that meadows are avoided by some species of small mammals and represent a barrier, while others overcome such areas. Alternatively, it is possible that the knee-high grass provided sufficient cover for M2 to move safely in this open area, as the forest ground was relatively uncovered. This may indicate that *M. roachi* will enter open land when there is sufficient grass height. It is not clear why M2 was repeatedly attracted to this open area. Given the time of year, it could be related to preparation for hibernation. Our results of significant weight gain in males are a good approach to evaluate food supply as a reason. Our observations suggest that *M. roachi* is a border species between forest and open land.

The results of the Jacobs index for the telemetry data also confirm a preference for the open area, supporting our findings that *M. roachi* is a border species. Analysis of the telemetry data showed that M2 preferred the open area PG15. These open areas were previously categorically excluded, as the animals were not expected here. However, individual traps or nest boxes were placed on oak trees in the middle of an open area. It can therefore be assumed that it is not atypical for *M. roachi* to cross open areas, as some detections were made on these trees (Nedyalkov, pers. comm.). However, preferences are strongly linked to wooded areas. This is shown by the results of the monitoring data. Furthermore, the behaviour of M2 contradicts these findings. This is because it did not simply cross the open area. Rather, this area was visited exclusively at night. It is therefore conceivable that in future trapping surveys some traps could be placed in the open spaces around the wooded areas. This could provide clear evidence of use. *M. roachi* is known to inhabit semi-open agricultural land with trees or bushes (Milchev & Georgiev 2012). Animals never stay in a habitat randomly and prefer a certain structure (Kenward 2001). The results of the Jacobs index are also consistent with previous findings that the species prefers oak and shrub habitats. A preference for open areas is not supported by the long-term monitoring data. An increase in site value can occur when resources are unequally distributed because animals have to travel long distances to meet their resource needs (Fritzell 1978). If resources are evenly distributed over a small area, the animal can satisfy its needs without having to travel long distances (Kenward 2001). This may explain why M2 was tracked only in the open area PG15. It can be assumed that his needs could be met in this area. These include sufficient shelter, but also the availability of nutrition. However, it should be noted that the data base for the Jacobs index is not entirely unbiased. Data from traps and nest boxes have been included in the calculation. Nest boxes are mainly used for resting, whereas trap data represent activity. A clear differentiation of these data sets might change the results. Nevertheless, these results show the importance of tree and shrub cover for this species, but also indicate that habitat requirements may not be as well understood as they might be. Buruldağ & Kurtonur (2001) found that the favourite foods were insects, spiders, snails, lizards, fruits, sunflower seeds and wheat. It is quite conceivable that M2 met the need for protein-rich animal food in the open area.

It is interesting to study certain preferences, as the results may well indicate which structures the animals prefer and which they tend to avoid (Braithwaite & Gullan 1978). Small mammals show a clear preference for certain conditions in their habitats (Canova 1992). According to binary logistic regression, none of the parameters measured in the field had a significant effect on the catchability of the site. The closest to the 0.05 significance level was soil exposure with 0.0735. It can only be speculated why none of the values are significant. It is possible that a larger number of samples would have led to a difference. No distinction was made between the two methods. This distinction might also make a difference to the results of the regression. This is due to time constraints. It is therefore quite possible that the results change as the level of detail of the variables increases. However, it is also possible that the parameters have no effect.

In general, the lower the detection probability, the wider the confidence intervals (Williams et al. 2002). It is therefore important to use a method of species detection that is appropriate and improves the probability of detection. In the case of *M. roachi*, live traps and nest boxes seem to be very suitable. The occupancy model also showed that the measured parameters had no influence. The zero model fitted the data best. The model was calculated for the sites regardless of the survey method. The aim was to get an overview of pure detection and occupancy rates. It is possible, however, that an occupancy model may detect a method difference and thus allow the method-dependent detection rates to be compared (Melcore et al. 2020). No statistically significant difference in catchability was found between traps and nest boxes. Therefore, both methods were combined. The estimated detection rate was 0.44. This means that almost every second animal in the study area is caught. It is possible that higher or lower detection rates could be obtained by changing or adding a method (Melcore et al. 2020). A major source of bias is false detections. This occurs when the species is not detected when it is present (MacKenzie et al. 2003). With more covariates to include, it is possible to look at what else influences detection. However, this would require a future study to build an occupancy model. Appropriate covariates would then need to be measured.

More meaningful results could be obtained by specifically collecting certain parameters (Mortelliti et al. 2014). The estimated occupancy rate is 0.718. This means that almost three quarters of all the sites tested are occupied by the species. This indicates a wide occupancy of the species in the study area. The empirical data showed an occupancy of 43.42%, as at least one individual could be detected at 33 of the 76 test sites. The results show that occupancy is higher than the evidence suggests. With a detection rate of 0.44 it is understandable that the estimated occupancy is higher than the data show. For the Japanese dormouse (*Glirulus japonicus*) a detection rate of 4.6% was achieved in a camera trap study. Occupancy was estimated at 18%. These results are still higher than the usual detection rates from nest boxes (Suzuki und Ando 2019). It may be that the detection rate also increases when camera traps are installed for an occupancy study. This could also make the occupancy estimate more accurate.

We have been able to show that there are fluctuations in the distribution of juveniles and adults between different years. The years 2019 and 2021 were dominated by juveniles. Fluctuations in the dominance of juveniles in the population may be explained by reproductive success not always being equal (Juškaitis 1994). This has been observed in *M. avellanarius* with strong fluctuations in the proportion of juveniles in the total population (Juškaitis 1994). It is possible that these fluctuations are related to food supply (Lebl et al. 2011). Bieber (1998) also found that *G. glis* adapts its reproduction to nutritional conditions. In years of low food availability, no juveniles could be detected. It is assumed that males do not invest energy in reproduction when feeding is poor. Based on our results, it can be concluded that the study area is subject to qualitative fluctuations that affect the composition of the population. Nedyalkov et al. (2022) found that the average litter size of *M. roachi* was 5-9 young. Reproduction occurred once a year. Compared to smaller, faster reproducing species such as *A. flavicollis*, where the average litter size was 4.1 (Massányi et al. 2003) or 3-6 (Gryczyńska-Siemiątkowska et al. 2008), the litter size of *M. roachi* is occasionally larger. However*, A. flavicollis* produces litters several times a year (Adamczewska 1961). The annual reproduction rate is relatively low, but as a dormouse *M. roachi* is dependent on high energy food.

Our results show that the oldest individual is at least four years old. It is known from *G. glis* that individuals can live up to seven, in some cases even up to nine years (Kryštufek et al. 2005b, Hoelzl et al. 2016). It is also known from *M. avellanarius* that some individuals can live up to five years (Juškaitis 2008). In rare cases even up to six years (Juškaitis 1999). There has been no confirmation of the death of the four-year-old individual so it is possible that the animal will be recorded again next season. These results give a first indication of the expected age of *M. roachi*.

The average weight of a newborn is 2.1g. By the time they take their first solid food, they weigh more than 7 g. After about a month, they leave their mother with a weight of just under 10 g. From then on, they are independent and have to survive on their own. After about 120 days they reach adult weight (Buruldağ & Kurtonur 2001). *M. roachi* must use the summer and autumn months to gain enough fat. This is also the case for other dormouse species (Juškaitis 2001). As the results show, the weight gain over the season is significant, except for adult females. Juškaitis (2001) found that *M. avellanarius* females are lighter than males when they emerge from hibernation. Adult male *M. roachi* are minimally heavier than females in the month of May. Juveniles also have similar weights in this month. The data show that there is a continuous increase in weight from month to month regardless of the demographic group. In June, the difference in weight between adult males and females is not significant. Females show a decrease in weight between June and July. This could be explained by pregnancy and the birth of young. The first young are born from the end of June (Nedyalkov et al. 2022). Juškaitis (2001) also found pregnancy-related weight differences in *M. avellanarius*. We have shown that *M. roachi* significantly increases its body weight during the active season in order to accumulate sufficient fat reserves for hibernation.

Our results show that the sex structure was in a state of flux. While more males were detected in the population in 2019 (57%) and 2020 (61%), more females were detected in 2021 (52%) and 2022 (53%). In these two years, however, the gender ratio is fairly balanced. No significant difference was found in any of the four years. The slight shifts could be coincidental. Sex ratios in small mammal populations may be affected by several mechanisms. One of the most important is sexual dimorphism in dispersal. Sexual dimorphism in habitat may be related to the limited use of habitat by females to find suitable nesting sites (Morris 1984). Male small mammals often have a higher risk of parasite infestation and consequent mortality (Morand et al. 2004). Pregnant or lactating females have a much higher energy requirement than males. This may lead to changes in habitat use. Females occupy larger areas or areas with higher quality resources (Diaz et al. 1999, Rosalino et al. 2011). In general, males emerge from hibernation earlier than females, as early as the end of April. Therefore, the recording of sex distribution is always a time-dependent variable. During these six months, the animals are active, reproduce once, and can theoretically be captured and observed.

However, it is possible that estivation may occur in the summer when temperatures are high (Nedyalkov et al. 2022).

The estimation of the population size using the POPAN parameterisation was carried out on an annual basis. The total population is estimated to be 77 ± 54 in 2021. Overall, the population fluctuates. The following year there are 54 ± 40 individuals estimated. In 2019 the population is larger than in 2020. However, despite a decrease, the population in 2022 is still larger than in 2019 or 2020. It is noticeable that the population is estimated to be smaller in the years when fewer juveniles are caught. This could be explained by changing microclimatic conditions, food supply or increased predation pressure (Batzli 1992). As such a study has never been carried out for this species before, there are no comparable data. The detection probability is constant over the study period and amounts to 0.77. For comparison: The occupancy model calculated a detection probability of 0.44. However, when catchability is good and the population is small, a large proportion of the population can be captured easily. The total number of individuals captured is 111. An additional 21 unmarked animals are estimated. Due to the high probability of detection, the unmarked superpopulation is comparatively small. The probability of entering the year of population growth is estimated to be 0.56. This can explain the growth, as animals are added to the population. In the years of population decline, the probability of entry is lower. As this value includes not only physical immigration into the population from outside, but also births, it is logically higher when the population is growing. Survival rates vary between 0.17 and 0.48 over the period. Thus, they are quite close to the survival rate of 0.38 for *E. quercinus* but exceed it (Schaub & Vaterlaus-Schlegel 2001). For *G. glis*, it was found that survival rates decrease when reproduction is increased (Lebl et al. 2011). If this is also the case for *M. roachi*, it could explain the low survival rate of 0.17 in the year with population growth between 2020 and 2021. As the survival rates in this thesis always refer to winter, an estimation of winter mortality can be made. In studies, *G. glis* could achieve seasonal survival rates above 0.8 (Lebl et al. 2011). Low mortality rates are typical for long-lived species (Bernotat & Dierschke 2016). In direct comparison, winter mortality seems to be higher. This may be due to starvation as a result of insufficient energy reserves (Lebl et al. 2011). Lower survival rates were also observed in *G. glis* when reproduction was high (Ruf et al. 2006). *G. glis* hibernates underground and can thus avoid predation almost completely (Büchner, pers. comm.). This explains the high survival rate. M2 was not active during the two nights of 8th - 9th October and 9th - 10th October. It spent the whole time in a tree hollow. We observed that the entrance was blocked with bark and twigs. This is typical behaviour for this species (fig. 29). One reason could be predation. *Tyto alba* and *Bubo bubo*, both of which occur in the area, have been found to feed on it. *Dolichophis jugularis* preying on *M. roachi* has been reported from Bulgaria. This species is commonly found in the region. There are also other snakes in the region such as *Vipera ammodytes*, *Elaphe sauromates*, *Malpolon insignitus*. During a camera trapping survey in the study area, *Martes foina* and *Felis silvestris* were recorded on the trees. They are potential predators and are likely to be preying on *Myomimus*. *Vulpes vulpes* and *Canis aureus* were also recorded (Nedyalkov, pers. comm.). As *M. roachi* is likely to hibernate in tree hollows and close the entrance, predation must play a role. Predation could also explain the relatively low survival rates compared to *G. glis*, as *M. roachi* may be more exposed to predators. The results suggest that predation occurs during the winter.

Figure 29: Nest box entrance closed by *M. roachi*. This behaviour is typical for this species to avoid predation. Picture: H. Queckenstedt

We were able to weigh the nests of *M. roachi* for the first time. The average nest weight was 317.5. Considering the weight of the nests, they are large in relation to the weight of the animals. Walhovd & Jensen (1976) weighed an *M. avellanarius* nest which weighed 7.0 g. It should be noted that these nests were dried before weighing. Hansen et al. (2023) found a variety of nest materials used for *M. avellanarius*. The four nests we weighed were also heterogeneous in composition. We found oak leaves, dry grass and small branches.

The results show that there is no significant difference in catchability between the two methods of nest boxes and traps. However, in 2021, the capture numbers from the nest boxes exceeded those from the traps. A possible reason for this could be that the animals needed time to get used to the change. This would seem logical as the animals use the nest boxes as a shelter and enter the traps to forage. It is possible that they initially avoided the nest boxes out of fear.

5 Conclusion

In summary, telemetry has been a success. Although fewer individuals were tracked than planned, new knowledge was gained. The intensive use of open areas by M2 provided previously unknown information, as the use of such areas had not been suspected before. The telemetry study could not show which hibernation sites were used. Our observations suggest that *M. roachi* is a border species between forest and open land. The monitoring data showed that *M. roachi* is dependent on forest areas and dense shrubs in its habitat. Therefore, these structures should be maintained and promoted to further conserve the species. Habitat fragmentation and loss are major causes of species decline and extinction. However, the role of adjacent open areas should be further investigated in the future to fill knowledge gaps. Nevertheless, it is imperative to conserve structurally rich areas within the range. The creation of biotope corridors is essential for the conservation of *M. roachi*. Without natural corridors, range expansion is unlikely. *M. roachi* has not yet been detected in the surrounding areas of this study. This does not mean that the species does not occur outside the study area, but the maintenance or creation of natural corridors may promote further dispersal. The occupancy model showed that almost three quarters of all sampling sites are occupied and the detection rate is 44%. It is therefore conceivable that by chance no individuals were found in neighbouring areas. In the future, camera traps could be increasingly used for detection, as they can reliably collect data over several weeks. It is conceivable that the targeted use of camera traps at the test sites could lead to different results for an occupancy model. The results of the population size estimates provide an insight into the variation in population size over the years. However, it is important to note that estimates may change if a targeted survey is undertaken. The results on demographics and weight gain provide an important data base that can be used for comparison in future studies. They also provide important basic knowledge. In addition, they provide important insights into the population structure. It was also shown that there were no significant differences between the two methods, nest box and trap, in terms of detection.

A renewed telemetry study in the study area would be useful to further improve our knowledge about this species. Genetic analysis to measure reproductive success could also yield promising results. In addition, a large-scale camera trap survey could be conducted to better understand circadian rhythms. It would also be important to learn about possible further occurrences and the diversity of the population through genetic analysis. There is a risk of low genetic diversity in such a small area. Basic research on the biology and ecology as well as on the causes of the endangerment is also needed. In order to reliably assess the current status of *M. roachi*, it is essential that research into the biology of this species continues at a high level.

6 References

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7 Appendix

1. Appendix: Field protocol

#	Time	WP/ GPS/ Angle: 1	WP/ GPS/ Angle: 2	Temperature/ Wind	Weather	View
1		____________ ____________ ____________	____________ ____________ ____________	____________°C ____________ (Beaufort scale)		☐ clear ☐ not clear
	Behaviour ☐ on the move ☐ Food ☐ Loud ☐ Interaction ☐ dormant	**Metre [m]** Distance to animal: ________ m Height of the animal: ____________ m		**Animal:** Seen? ☐ yes ☐ no Heard? ☐ yes ☐ no		
		Comment Structure:____________Vegetation:____________ Other:____________ ____________ ____________				
#	**Time**	**WP/ GPS/ Angle: 1**	**WP/ GPS/ Angle: 2**	**Temperature/ Wind**	**Weather**	**View**
2		____________ ____________ ____________	____________ ____________ ____________	____________°C ____________ (Beaufort scale)		☐ clear ☐ not clear
	Behaviour ☐ on the move ☐ Food ☐ Loud ☐ Interaction ☐ dormant	**Metre [m]** Distance to animal: ________ m Height of the animal: ____________m		**Animal:** Seen? ☐ yes ☐ no Heard? ☐ yes ☐ no		
		Comment Structure:____________Vegetation:____________ Other:____________ ____________ ____________				
#	**Time**	**WP/ GPS/ Angle: 1**	**WP/ GPS/ Angle: 2**	**Temperature/ Wind**	**Weather**	**View**
3		____________ ____________ ____________	____________ ____________ ____________	____________°C ____________ (Beaufort scale)		☐ clear ☐ not clear
	Behaviour ☐ on the move ☐ Food ☐ Loud ☐ Interaction ☐ dormant	**Metre [m]** Distance to animal: ________ m Height of the animal: ____________ m		**Animal:** Seen? ☐ yes ☐ no Heard? ☐ yes ☐ no		
		Comment Structure:____________Vegetation:____________ Other:____________ ____________ ____________				
#	**Time**	**WP/ GPS/ Angle: 1**	**WP/ GPS/ Angle: 2**	**Temperature/ Wind**	**Weather**	**View**
4		____________ ____________ ____________	____________ ____________ ____________	____________°C ____________ (Beaufort scale)		☐ clear ☐ not clear
	Behaviour ☐ on the move ☐ Food ☐ Loud ☐ Interaction ☐ dormant	**Metre [m]** Distance to animal: ________ m Height of the animal: ____________ m		**Animal:** Seen? ☐ yes ☐ no Heard? ☐ yes ☐ no		
		Comment Structure:____________Vegetation:____________ Other:____________ ____________ ____________				

2. Appendix: Jacobs Index

Appendix: Table 1: Individual sizes of the polygones

Polygon	**Size [m^2]**
PG1	6870.76
PG2	3809.93
PG3	6997.12
PG4	9824.13
PG5	7268.45
PG6	2752.34
PG7	3041.63
PG8	69288.92
PG9	63995.43
PG10	56708.54
PG11	12851.35
PG12	16220.02
PG13	10536.60
PG14	1707.54
PG15	6048.84
Total	279918.76

STATUTORY DECLARATION

Hereby I, Hendrik Queckenstedt, declare that I have written the thesis

Population dynamics, habitat use,
and telemetry studies of *Myomimus roachi*

independently and that I have not used any auxiliary materials and sources other than those indicated.

The work has not been submitted to any other examination authority and has not been published.

Examination location, deadline Signature