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Spatial behaviour of yellow-necked wood mouse *Apodemus flavicollis* in two sub-Mediterranean oak coppice stands

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Running head: Spatial behaviour of *Apodemus flavicollis*

Abstract

Strong mutual relationships exist between rodents and ecosystems. By modifying the structure and functioning of ecosystems, human activity can affect rodent behaviour and ecology. The yellow-necked mouse *Apodemus flavicollis* is widespread in Europe and its spatial ecology has been studied in various habitats, but studies are lacking for Mediterranean forests often altered by forest management practices. We investigated the spatial behaviour of *A. flavicollis* in a sub-Mediterranean deciduous oak forest of central Italy subject to forest management. We radio-tracked 27 individuals in two different coppice stands, i.e. a recently cut area and a high forest, differing in terms of species-specific habitat quality and rodent population density. We analysed the size of home ranges in relation to habitat type and sex. Our results revealed that home range and core area size did not differ between habitat types or sexes. The spatial behaviour of *A. flavicollis* thus did not appear to be influenced by population density and habitat quality. The lack of sex-related differences confirms the current knowledge on the species' spatial ecology. Our findings provide the first useful information on the spatial behaviour of *A. flavicollis* in sub-Mediterranean deciduous oak forests, whose ecological processes may be markedly influenced by this key-species at several trophic levels.

Keywords: radio-tracking; oak forest; home range; forest management; rodent

Conflicts of interest/Competing interests

The authors declare that they have no competing interests.

Ethics approval

All the procedures undertaken on small mammals took place in compliance with the European Council Directive 92/43EEC (Italian law D. Lgs 157/92 and LR 3/1994) and with the European Council Directive 86/609/EEC (Italian law D. Lgs 116/92).

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

INTRODUCTION

By modifying natural habitats, humans are altering the structure and functioning of ecosystems, thus affecting animal behaviour and ecology (Debinski and Holt, 2000; Wong and Candolin, 2015). Animals typically alter their movement behaviour as they adapt to changes in resource availability and landscape structure, therefore habitat modification can sensibly alter animal movement (Doherty and Driscoll, 2018). This can entail ecological consequences in the case of rodents, as they are commonly among the main preys of upper-trophic-level species (Smith and Slatkin, 1973; Hanski et al., 2001), and they act as one of the major seed dispersers and consumers among mammals (Stiles, 2000). Given the strong mutual relationships between rodents and ecosystems (Smith and Slatkin, 1973; Hanski et al., 2001), it is important to investigate rodents' spatial ecology through the different habitat types they occupy.

The yellow-necked mouse *Apodemus flavicollis* is a mainly granivorous species (Butet and Delettre, 2011), widespread in Europe from Finland to Turkey, with a more reduced and fragmented range in southern Europe (Harris and Yalden, 2008). Studies on the spatial behaviour of this rodent were carried out in different habitats in temperate, continental and Alpine areas of Europe, where the species' home range varies considerably in size (Montgomery, 1979; Schwarzenberger and Klingel, 1995; Vukićević-Radić et al., 2006; Stradiotto et al., 2009). However, studies on spatial behaviour of *A. flavicollis* and information on its home range characteristics in Mediterranean forests are still lacking.

Variation in home range characteristics can generally be attributed to biological factors such as sex and population density and to environmental variables such as food and shelter availability (McLoughlin and Ferguson, 2000). Accordingly, the home range of *A. flavicollis* is known to vary in relation to biological factors, syntopy with ecologically similar rodents and differences in resource availability in relation with habitat quality (Vukićević-Radić et al., 2006; Stradiotto et al., 2009). Males generally have larger home ranges than females and greater range overlaps with individuals of both sexes (Stradiotto et al., 2009). Marked reductions in home range size of *A.*

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flavicollis were observed by Casula et al. (2019) at high intraspecific densities and by Vukićević-Radić et al. (2006) also at high densities of other potentially competitive rodent species. Indeed, population density is generally considered one of the main factors affecting home range features in rodents (Schoepf et al., 2015). In addition, it is known that habitat quality can markedly influence home range size of rodent species, with smaller home ranges in higher-quality habitats (e.g. Briner et al., 2005; Steinmann et al., 2005; Dracup et al., 2015).

Mediterranean oak-dominated forests are commonly managed by coppicing, a forest management system aimed at wood production and involving practices that affect habitat quality (Gurnell et al., 1992). Consequently, by modifying vegetation structure and stand composition, forest management can alter habitat quality and, thus, affect the ecology and population parameters of the forest-specialist *A. flavicollis* (Wołk and Wołk, 1982; Gurnell et al., 1992; Capizzi and Luiselli, 1996; Gasperini et al., 2016). In a previous study we reported that, in central Italy, coppicing can entail positive effects on population parameters of *A. flavicollis* by increasing habitat quality (Gasperini et al., 2016). Thus, forestry-driven alterations of habitat quality in managed forests can also have important effects also on the species' spatial behaviour.

In this light, we investigated the spatial behaviour of the yellow-necked mouse by radio tracking in a coppiced sub-Mediterranean deciduous oak forest of central Italy, where the species is a major consumer and disperser of *Quercus* spp. acorns. We focused on the size of home ranges in relation to habitat type (i.e. coppiced stands) and sex. We selected two coppiced stands previously investigated (Gasperini et al., 2016) and characterized by a different habitat quality, differing not only in their structure and composition but also in terms of resource abundance and intra- and inter-specific rodent population densities. Consequently, we expected home range size to differ between habitat types. In particular, we expected size to decrease in the habitat type considered to be more suitable for the species and characterized by higher intra- and inter-specific population densities. In addition, given the socio-spatial organisation of the species, we expected males to occupy larger ranges than females.

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METHODS

Study area

This study was carried out in *La Selva* Forest (43° 13' N, 11° 4' E), located 45 km from Siena, in Central Italy. The altitude ranges from 350 to 700 m a.s.l., and the climate is Mediterranean, with warm dry summers and cool wet winters. Mean monthly temperature is about 23°C in summer and about 4°C in winter, with average annual rainfall of about 750-1600 mm. The main land cover consists of oak woodland of the sub-Mediterranean zone, dominated by the Turkey oak *Quercus cerris* and traditionally managed for coppice. Ground-dwelling small mammals acting as potential competitors of yellow-necked mouse in the study area are the wood mouse *A. sylvaticus* and the bank vole *Myodes glareolus* (Gasperini et al., 2016). Several species of mesocarnivores, raptors and ophids are common predators of *A. flavicollis* in our study area. Our study focused on two previously sampled sites, located about 3 km apart inside the oak-dominated woodland and differing mainly for their stage of regrowth (Gasperini et al., 2016). The first site is a recently coppiced area (hereafter "RC"), last cut about 5 years prior to this study and characterized by low stand density. The second site is located in a zone where passive conversion by ageing of coppice (*sensu* Nicolescu et al., 2017) has led to a high forest (hereafter "HF"), which had been logged more than 30 years ago and is now dominated by high and relatively old trees. Each management type is characterized by contrasting availability of resources, namely RC has higher shrub cover and fruit production but lower acorn production than HF (Gasperini et al., 2016). Based on spatially explicit capture-recapture analyses of extensive live-trapping data, we estimated that the population density of yellow-necked mice was nearly three times higher in RC than in HF (Gasperini et al., 2016). Moreover, *A. flavicollis* was found to live in syntopy with the wood mouse *A. sylvaticus* and the bank vole *M. glareolus* in RC, whereas in HF no voles were ever captured and wood mice were present only at very low densities (Gasperini et al., 2016).

Trapping and handling

From December 2013 to October 2014, we live-trapped small mammals every other month in each site with 30 Sherman traps (Sherman H.B. Inc, Aluminum Folding Trap), baited with sunflower seeds and peanut butter, and filled with hemp nesting material. Each trap was placed opportunistically (i.e. where we thought vegetation cover to be fitting the species microhabitat requirements) every 10 m ca., along transects of length ≤ 50 m and about 10 m apart from each other. We checked the traps every morning during each session, which lasted three days on average. Yellow-necked mice were weighed, sexed, aged and breeding condition was assessed (Bartolommei et al., 2016). We used adults with no evidence of reproductive activity and weighing over 20 g to ensure the VHF transmitter weight would not alter the behaviour (White and Garrott, 1990). We immediately released individuals not suitable for the study at the place of capture.

Each suitable animal was transferred into a plastic box (0.1 m × 0.1 m × 0.2 m) containing an ether-soaked pad hanging from the top. We kept the animal in this container for the time necessary for the aerosol to induce a light anaesthesia. We then fitted the mouse with unique frequency VHF (in the range 151.100 – 151.900 Hz) collar transmitters (BD-2C model – Holohil Systems, Ltd., Ontario, Canada; weight: 1.5 g). We individually marked every collared specimen by cutting a small fragment of auricular tissue. This was necessary to recognise tracked animals in the following capture sessions (see the section below). The same sample of ear tissue was used to confirm the field identification of species by molecular analyses, as the visual identification of *A. flavicollis* and its sister species *A. sylvaticus* is particularly challenging in southern Europe (for details see Bartolommei et al., 2016). After collaring the animals, we kept them in a plastic cage (0.6 m × 0.4 m × 0.3 m) sheltered in a structure located in the forest, to ensure they had fully recovered from the sedation and radio-collars were correctly fit. Ultimately we released each animal at its point of capture, before the sunset to avoid altering the daily activity rhythm of the species (Wójcik and Wołk, 1985).

All the procedures undertaken on small mammals took place in compliance with the European Council Directive 92/43EEC (Italian law D. Lgs 157/92 and LR 3/1994) and with the European

Council Directive 86/609/EEC (Italian law D. Lgs 116/92).

Radio tracking

Radio tracking started on average three days after animal release. We regularly located collared mice using triangulation technique (White and Garrott, 1990) with a three-element directional Yagi antenna and Sika receiver (Biotrack, Dorset, UK). We radio-located individuals continuously from dusk to dawn. We took individual bearings at maximum 5-min intervals, with location recorded at 30-min intervals. We radio-tracked mice until the device / battery failed or until we found evidence that the animal had died. At the end of the tracking sessions, we recaptured the mice to retrieve the collars. We did not find any sign of injury or significant weight loss in recaptured animals. In case of dead animals (n = 10), we retrieved the collars with the homing technique. A total of 1417 fixes were collected during 29 tracking sessions. The tracking period (i.e. time between first and last recorded location) for used animals averaged 16 days (SE = 1.2).

Home range size

We calculated the size of each individual home range and core area by perturbative hybrid residual maximum likelihood estimation (pHREML, Fleming et al., 2019) of continuous-time movement models (Blackwell, 1997; Johnson et al., 2008) at 95% and 50% coverage level, respectively. Continuous-time movement models relying on pHREML estimation are accurate even with small effective sample sizes (Fleming et al., 2019). To estimate the variance and enhance the reliability of our home range estimates (Powell, 2000), we performed a parametric bootstrap, as described in Fleming et al (2019).

We included 27 animals in the analysis with a mean number of locations per specimen of 48.9 ± 4.3 SE (Table 1). Fourteen mice were tracked in RC (nine males and five females) and 13 (seven males and six females) in HF (Table 1).

Although not all individuals were tracked in the same period and during the same time span, we calculated the overall home range of each individual to estimate the median individual range (95% pHREML and 50% pHREML). This allowed us to compare our results with those reported in other

studies on the spatial ecology of *A. flavicollis* (Montgomery, 1979; Schwarzenberger and Klingel, 1995; Vukićević-Radić et al., 2006; Stradiotto, 2008).

Data analysis

All analyses were carried out data in R (R Core Team, 2018). We estimated the home range size with package *ctmm* (Fleming and Calabrese, 2019) and visualized it in Quantum GIS (QGIS Development Team, 2017). We assessed habitat- and sex-related differences in home range size using an Asymptotic Wilcoxon-Mann-Whitney Test from package *coin* (Zeileis et al., 2008).

RESULTS

Individual home range varied from 0.25 to 1.55 ha for males, and from 0.32 to 1.72 ha for females (median 0.78 and 0.74, respectively) (Table 1). The core area represented 23 % of the home range for males (min 17 %, max 29 %) and 24 % for females (min 18 %, max 29 %) (Table 1).

The size of home ranges did not differ significantly between RC (median = 0.77 ha, IQR = 0.61 – 1.00 ha, N = 16) and HF (median = 0.73 ha, IQR = 0.51 – 1.32 ha, N = 14) (asymptotic Wilcoxon test, Z = 0.41, p = 0.68). This lack of significant habitat-related differences in size was observed also for the core areas (RC: median = 0.19 ha, IQR = 0.13 – 0.22 ha, N = 16; HF: median = 0.16 ha, IQR = 0.14 – 0.26 ha, N = 14) (asymptotic Wilcoxon test, Z = 0.21, p = 0.84).

The size of home ranges was not different between males (median = 0.84 ha, IQR = 0.54 – 1.13 ha, N = 18) and females (median = 0.76 ha, IQR = 0.59 – 1.16 ha, N = 12) (asymptotic Wilcoxon test, Z = 0.21, p = 0.83). The same is true also for core area size, which did not differ significantly between sexes (males: median = 0.19 ha, IQR = 0.13 – 0.24 ha, N = 18; females: median = 0.18 ha, IQR = 0.14 – 0.24 ha, N = 12) (asymptotic Wilcoxon test, Z = 0.21, p = 0.84).

A summary of home range and core area size values grouped by habitat and sex is reported in Fig. 1.

DISCUSSION

We investigated the spatial ecology of *A. flavicollis* in two sub-Mediterranean oak coppice stands, by focusing on home range size of mice. Compared to the available studies based on radio-tracking (i.e. yielding comparable results; White and Garrott, 1990), our estimates of home range size for *A. flavicollis* are similar to those found by Stradiotto et al. (2009) and Schwarzenberger and Klingel (1995), even though both studies were led in habitats that are structurally and compositionally different from sub-Mediterranean deciduous oak forests.

In coppice woodlands, *A. flavicollis* has been observed to prefer older compartments and to avoid recently coppiced areas, where lower abundances of yellow-necked mice were recorded (Gurnell et al., 1992, Capizzi and Luiselli, 1996). However, in a previous study on *A. flavicollis* population parameters in relation to forest management (Gasperini et al., 2016), we reported that, in our study area, recently coppiced stands represent a habitat of higher quality, while the older stands resulted to be less-suitable. In addition, these habitats were also characterized by strongly different intra- and inter-specific population densities, which were markedly higher in RC. Consequently, based on the knowledge of *A. flavicollis* space use variations according to population densities and habitat quality (Montgomery, 1979; Schwarzenberger and Klingel, 1995; Vukićević-Radić et al., 2006; Stradiotto et al., 2009; Casula et al., 2019), we expected the two habitat types to differ significantly in their home range and core area attributes. In particular, we expected that home range and core area size would be smaller in the habitat with higher population densities and higher habitat quality. However, as observed for other rodent species (e.g. Coleman and Downs, 2010; Korbelová et al., 2016; Mlyashimbi et al., 2020), our results revealed that home range and core area size were not significantly influenced by habitat type. Although changes in spatial patterns with population density are well documented in several rodent species (Wolff, 1996; Mazurkiewicz and Rajska-Jurgiel, 1998; Stradiotto et al., 2009), this habitat-specific attribute did not seem to determine differences in home range size of *A. flavicollis* in our study. In fact, despite the markedly different population densities of ground-dwelling rodents between RC and HF, we did not find any significant reduction in home range size at high intra- and inter-specific densities, differently from

what observed by Casula et al. (2019) and Vukićević-Radić et al. (2006). Given the similar spatial behaviour of mice we tracked in HF and RC, our results also suggest that habitat quality did not rule the species' home range size. Although coppiced stands of different habitat quality can entail strong effects on population parameters (Gasperini et al., 2016), it is therefore possible that habitat quality exerts a stronger effect on the demography of *A. flavicollis* rather than on its spatial behaviour in our study area. Nonetheless it is possible that by exploring the spatial behaviour of *A. flavicollis* seasonally we could have found relevant temporal differences between home ranges in RC and HF. A seasonal analysis of radio tracking data could have put into light how mice adjust their home range sizes differently according to several time-related parameters such as the ongoing habitat-specific resource availability, the breeding season and the current population density. In addition, we cannot exclude that other site-specific factors (e.g. local predator pressure) might have influenced our results as well, as our study was performed in a single site per habitat type.

Contrary to our expectations, home range and core area size was not primarily related to yellow-necked mice sex either. Some studies found bigger home ranges for males than for females, although without statistical support (Montgomery, 1979; Schwarzenberger and Klingel, 1995; Vukićević-Radić et al., 2006; Casula et al., 2019). Only Stradiotto et al. (2009) models revealed that sex was important for size changes in home range and core area. In our study, it is possible that a more relevant role of sex could have emerged by including sexually active individuals in the sample of mice we radio-tracked. Likewise, it is also possible that the role of sex was dampened by the large individual variability (Table 1), similarly to Schirmer et al. (2019) that showed a stronger role of personality in determining the spatial behaviour of an ecologically similar rodent species.

Our study suggests that *A. flavicollis* home range and core area size was not influenced by habitat type and sex, although we acknowledge our results should be taken with caution due to our small sample sizes and lack of spatial replicates. Further studies performed with bigger sample sizes and in multiple sites per habitat type are thus needed to confirm and enrich our findings. Studies encompassing seasonality and additional factors known to influence *A. flavicollis* spatial behaviour,

such as the genetic relatedness of individuals (Bogdziewicz et al., 2016) and the breeding activity (Schwarzenberger and Klingel, 1995), would also give a deeper insight into the species' spatial ecology. Nevertheless, our findings provide the first useful information on the spatial behaviour of this species in sub-Mediterranean deciduous oak forests, which may markedly influence ecosystem processes at several trophic levels in sub-Mediterranean forests.

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Table 1 Summary of radio-tracking sessions, number of locations collected and values of home range size estimators of 27 *Apodemus flavicollis* tracked in two coppiced stands of sub-Mediterranean deciduous oak wood. The first letter of animal ID refers to its sex ("F" = female; "M" = male)

	Recent coppice (RC)				High forest (HF)		
ID	Locations (n)	95 % pHREML (ha)	50 % pHREML (ha)	ID	Locations (n)	95 % pHREML (ha)	50 % pHREML (ha)
F01	61	1.15	0.27	F07	56	0.32	0.07
F02	51	0.65	0.19	F08	45	0.75	0.16
F03	42	0.35	0.1	F09	35	0.66	0.14
F04	67	0.73	0.16	F11	47	1.72	0.45
F05[a]	93	0.77	0.19	F12	21	0.42	0.11
F05[b]	103	1.15	0.27	F13	27	1.22	0.22
M01	48	1.18	0.2	M11[a]	43	1.11	0.23
M02	60	1.09	0.26	M11[b]	30	1.41	0.31
M03	42	0.36	0.08	M12	22	0.31	0.08
M04	103	0.65	0.15	M13	20	1.2	0.26
M05	54	0.94	0.22	M15	20	0.39	0.09
M06	50	0.7	0.17	M16	30	1.55	0.29
M07	67	0.5	0.11	M17	41	0.53	0.13
M08	59	0.89	0.18	M18	20	0.41	0.12
M09	60	0.86	0.2				

[a] June radio-tracking session
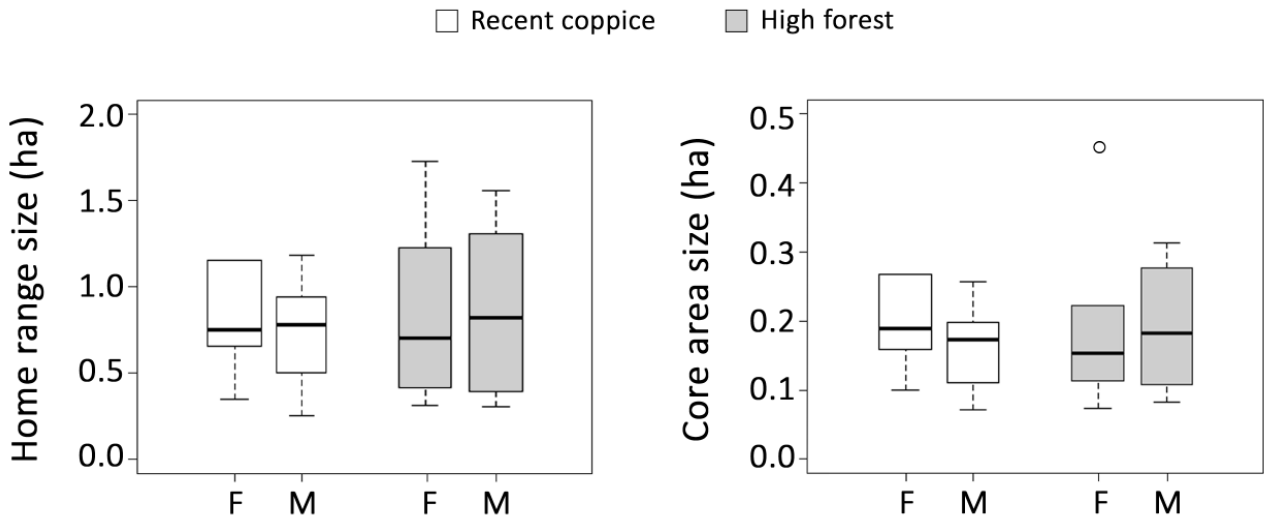[b] February radio-tracking session

Fig. 1 Home-range and core-area size of 27 *Apodemus flavicollis* tracked in two coppiced stands of sub-Mediterranean deciduous oak wood. Values reported are grouped by sex ("F" = female; "M" = male). Estimates of home ranges and core areas were generated using perturbative hybrid residual maximum likelihood (pHREML) at 95% and 50% coverage level, respectively. The plot illustrates the median (middle line), interquartile range (top and bottom of each box), 5th and 95th percentile (whiskers) and outlier (open circle)