Ranging behavior of European rabbits (Oryctolagus cuniculus) in urban and suburban landscapes

Madlen Ziege, Bernd Timo Hermann, Stefanie Kriesten, Stefan Merker, Wiebke Ullmann, Bruno Streit, Sandra Wenninger & Martin Plath

ONLINE
FIRST

Springer

Springer

SHORT COMMUNICATION

Ranging behavior of European rabbits (*Oryctolagus cuniculus*) in urban and suburban landscapes

Madlen Ziege[1,2] · Bernd Timo Hermann[2] · Stefanie Kriesten[1] · Stefan Merker[3] · Wiebke Ullmann[4] · Bruno Streit[1] · Sandra Wenninger[1] · Martin Plath[5]

Abstract

Various mammals, particularly carnivores, reportedly establish smaller home ranges in urban compared with rural areas. This may be because urban environments provide optimal resources within a small area, negating the requirement to range further, or because habitat fragmentation constrains ranging behavior. Comparable information on urban populations of herbivorous mammalian species (such as European rabbits) is scarce. To fill this knowledge gap, we radio-tracked 13 individuals (seven females and six males) equipped with radio collars in a suburban and an urban study site in the city of Frankfurt am Main in Germany during the reproductive season (March to September) of 2012. The study sites differed in levels of habitat fragmentation. We report the smallest home ranges ever described for this species, with mean 95% minimum convex polygons (MCPs) covering 0.50 ha, while no consistent differences between sites were uncovered. We occasionally tracked individuals crossing streets underground (in burrows), suggesting that streets may restrict the ranging behavior of rabbits—and possibly other burrowing species—to a much lesser extent than previously thought. We conclude that heterogeneous landscape structures, made up of a diverse mosaic of buildings, parks, and gardens, provide sufficient food and shelter in close proximity to burrows at both study sites. Therefore, our data support the hypothesis that optimal resources constrain ranges in this case rather than habitat fragmentation.

Keywords Habitat fragmentation · Home range · Urbanization · Urban ecology · Minimum convex polygons (MCPs)

Introduction

Key factors influencing individuals' ranging behavior are the distribution of resources (such as food or access to breeding sites), as well as the density and distribution of conspecifics, heterospecific competitors, and predators (Adkins and Stott 1998; Prange et al. 2003, 2004; Ryan and Partan 2014). For several species, urban ecosystems provide higher and more constant food availability,

Communicated by: Magdalena Niedziałkowska

✉ Madlen Ziege
  madlen.ziege@mailbox.org

  Stefanie Kriesten
  kriesten@bio.uni-frankfurt.de

  Stefan Merker
  stefan.merker@smns-bw.de

  Wiebke Ullmann
  wiebke.ullmann@uni-potsdam.de

  Bruno Streit
  streit@bio.uni-frankfurt.de

  Sandra Wenninger
  sandra.wenninger@tieroekologie.com

  Martin Plath
  mplath-zoology@gmx.de

1   Department of Ecology & Evolution, University of Frankfurt, Max-von-Laue-Str. 13, 60438 Frankfurt am Main, Germany

2   Berlin, Germany

3   Department of Zoology, State Museum of Natural History Stuttgart, Rosenstein 1, 70191 Stuttgart, Germany

4   Department of Plant Ecology and Nature Conservation, University of Potsdam, Am Mühlenberg 3, 14453 Potsdam, Germany

5   College of Animal Science and Technology, Northwest A&F University, Yangling 712100, Shaanxi, China

🙂 Springer

both in the form of human waste and through deliberate feeding (Niemelä 1990; Kowarik 2011; Šálek et al. 2015). In conjunction with reduced predation pressure (birds: Møller 2008; fox squirrels: McCleery et al. 2008; but see "predation paradox": Shochat et al. 2006 for contrasting results), longer vegetation and reproductive period factors (Partecke et al. 2004; Ditchkoff et al. 2006) as well as reduced migratory behavior (in birds: Jokimäki and Suhonen 1998; Møller 2008) result in higher populations densities (Prange et al. 2003; Shochat et al. 2006; Rodewald and Gehrt 2014) and thus, heightened intra-specific competition for space and resources (Hutchings et al. 2002; Schley et al. 2004; Ziege et al. 2016).

Tucker et al. (2018) related the Human Footprint Index (HFI) to radio tracking data of 803 individuals across 52 different mammalian species. The HFI is an index with a global extent that combines multiple proxies of human influence. It was calculated based on the extent of built environments, crop and pastureland, human population density, nighttime lights, railways, roads, and navigable waterways (for more details see Venter et al. 2016 and Tucker et al. 2018). An HFI value of zero represents natural environments (e.g., the Brazilian Pantanal) and values of up to 50 represent anthropogenically transformed environments with high human densities (e.g., New York City; Tucker et al. 2018). The authors reported that ranging distances in areas with a comparably high HFI (up to 35) were on average one-half to one-third of those found in conspecifics that live in areas with a low HFI (< 10).

Most studies on home range use of urban wildlife have focused on carnivorous species, such as red foxes, bobcats (*Lynx rufus*), or stone martens (*Martes foina*; reviewed in Šálek et al. 2015). Our present study was designed to provide novel insights into the question of how a medium-sized, herbivorous mammalian species—the European rabbit (*Oryctolagus cuniculus*, L. 1758)—might change its home range use in urban environments. Like the aforementioned carnivores, European rabbits can reach comparatively high population densities in cities (Ziege et al. 2013, 2015; Arnold et al. 2016).

The spread of the viral diseases myxomatosis in 1952 and rabbit hemorrhagic disease (RHD) in the early 1980s, in combination with the continued loss of structural diversity in rural landscapes, led to starkly declining population dynamics or even local extinctions of European rabbits in rural areas of Europe, including Germany (Lees and Bell 2008; Arnold et al. 2016). Nevertheless, until today, no study has quantified home range dimensions of urban European rabbit populations. Our study fills this gap of knowledge and contributes to our understanding of how European rabbits—once common and widespread in Germany but now for many regions restricted to urban environments (Arnold et al. 2016)—make use of urban landscapes.

Based on the abovedescribed anthropogenic impacts within our study sites, we addressed two hypotheses. (1) We predicted home range dimensions of urban and suburban European rabbits in Frankfurt to be considerably smaller compared with previously reported values for European rabbits living in rural areas. More specifically, we expected 95% MCP values to be even smaller than 0.7 ha—the smallest value reported for European rabbits ($n = 16$) inhabiting favorable rural landscapes in France (i.e., cultivated open land characterized by mixed farming and hedgerows) during the reproduction season (Devillard et al. 2008). (2) We further hypothesized that if habitat fragmentation is a major determinant of home range dimensions, then rabbits from the urban study site should have even smaller home ranges than those from our suburban study site. At the urban study site, habitat available to European rabbits is even more fragmented by streets and pathways that potentially restrict their natural ranging behavior.

Materials and methods

Study populations and sampling sites

Based on records from the city archive, rabbit populations have been established in Frankfurt am Main at least since the 1930s (Stadtarchiv Frankfurt). Frankfurt is the largest city in the state of Hesse and the fifth-largest city in Germany (Brinkhoff 2016), about 736,000 people live in the city's administrative boundaries and about 2.4 million in its functional urban area, with an average density of 3000 inhabitants per square kilometer (Brinkhoff 2016). Nonetheless, Frankfurt is considered a "green city" since more than 58% of the area within the city limits are protected green areas (e.g., forest, parks, and gardens; Berliner Morgenpost, October 5,2016). We originally radio-collared 8 rabbits (4 males and 4 females) in a green area (*Friedberger Anlage*) in the city center (N 50°7.04 E 8° 41.5; 4.9 ha; Figs. 1 and 2) and 9 rabbits (5 males and 4 females) in a suburban park (*Rebstockpark*) located in the periphery of Frankfurt (N 50°6.674 E 8°36.773; 11 ha; Figs. 1 and 2; Table 1). At both sites, short-cut meadows were the dominant landscape element, with a grass cutting regime of up to once a week during summer. As mentioned above, both study sites differed in the overall "degree of urbanization" (Ziege et al. 2013).

We tracked radio-collared individuals from urban and suburban sites in the city of Frankfurt am Main to determine their home range dimensions. In previous studies, we assessed various parameters of different study sites in and around Frankfurt that were related to anthropogenic influence and summarized them by means of a factor reduction (i.e., principal component analysis), resulting in principal components that characterized the "degree of urbanization" (for more details see Ziege et al. 2013). Specifically, we assessed the proportion of artificial ground cover (e.g., streets and playgrounds) and numbers of anthropogenic objects per hectare (e.g., benches and street lamps). Our study sites clearly

Fig. 1 Suburban study site (*Rebstockpark*, left circle) and urban study site (*Friedberger Anlage*, right circle) in Frankfurt Main, Germany. Source: Google Earth

differed in the availability of continuous living space, with mean percentages of anthropogenic cover making up 17.1% in the urban area but only 10.6% in the suburban area. Numbers of anthropogenic objects per hectare were determined as 20 in our urban study area and 12 in the suburban area. We further obtained information on the direct intensity of disturbance by humans (pedestrians and bikers) and leashed or unleashed dogs (per minute and hectare) that rabbits were exposed to during their main activity periods at dusk and dawn through transect counts (for more details see Ziege et al. 2013, 2015). Mean values for our measure of disturbance per minute and hectare were as high as 0.64 in the urban, but only 0.09 in the suburban study area. Additionally, we obtained data on numbers of human residents located within a radius of 500 m from the borders of the study sites from the registration office of Frankfurt (*Einwohnermeldeamt*, updated: October 31,2010) to provide an estimate of overall and peak numbers of visitors in the park areas, as residents tend to walk in nearby city parks. The number of residents within 500 m was 4713 at the urban compared with 418 at the suburban study site.

Capture of animals and radio tracking

During the hunting period from October to March, rabbits are hunted by certified hunters employed by the city of Frankfurt with an exclusive hunting license for selected parks inside the city. We took advantage of a hunting method called "ferreting" to catch rabbits in March 2012. We used domestic ferrets (*Mustela putorius furo*) to drive rabbits out of their burrows into wire cages placed into the burrow entrances (cages were self-build by the responsible hunter). We noted the sex of captured individuals and weighed them inside a linen sack. Body weight served as a rough estimate of age, and only adult individuals were collared (> 1220 g; see Kolb 1991). We equipped hand held rabbits with PD-2C radio collars (Holohil Systems, Carp, Canada; 4 g total weight) and afterwards released them at the capture site. We started data collection 1 week after this

procedure to allow freshly collared specimens to recover from capture stress (Zollner et al. 2000). Individual location fixes were collected during five randomly selected days per week by several research assistants at both sites simultaneously. Data collection took place either between 06:00 a.m. and 02:00 p.m. or between 02:00 p.m. and 09:00 p.m., based on the flip of a coin (Zollner et al. 2000), from March to September 2012. Two times a week, we also collected location fixes between 09:00 p.m. and 06:00 a.m. The location of each focal individual was recorded at least once between 06:00 a.m. and 09:00 p.m. and at least twice during 09:00 p.m. and 06:00 a.m. until death of the collared individuals or transmitter failure (Zollner et al. 2000). We used antennae and receivers from Biotrack Ltd. (Wareham Dorset, UK) and Telonics Inc. (Mesa, AZ, USA) to locate focal individuals using a combination of triangulation and "homing in" (Garrott and White 1990). This included cases in which individuals were located underground (in burrows). We noted the time at which location fixes were taken (noted first into a high-resolution physical map and later transferred into GPS coordinates). Moreover, we noted the overall weather conditions for the day, i.e., temperature and precipitation gained from the daily weather forecast as well as the current weather situations at the time we took the location fixes, i.e., using a digital outside thermometer and noting the following variables: cloudy (yes/no), rain (yes/no), and sunshine (yes/no). All experimental procedures described here were in accordance with the current laws on animal experimentation in Germany and the European Union (hunting license 1000250221; ID: V54-19c 20/15 – F 104/59).

Statistical analyses

After visual inspection of asymptotic area-observation plots using the incremental area function in Ranges v. 8 (Kenward 1990; Nilsen et al. 2008), we decided to include only individuals with a minimum number of 95 fixes per individual. We obtained a sufficient number of location fixes for 4 females

Fig. 2 Kernel density estimates (95% and 50% KDEs) of 8 animals in the suburban study site (*Rebstockpark*) (**a**) and 5 animals in the urban study site (*Friedberger Anlage*) (**b**). Full-line circles indicate male individuals; dashed-line circles, female individuals
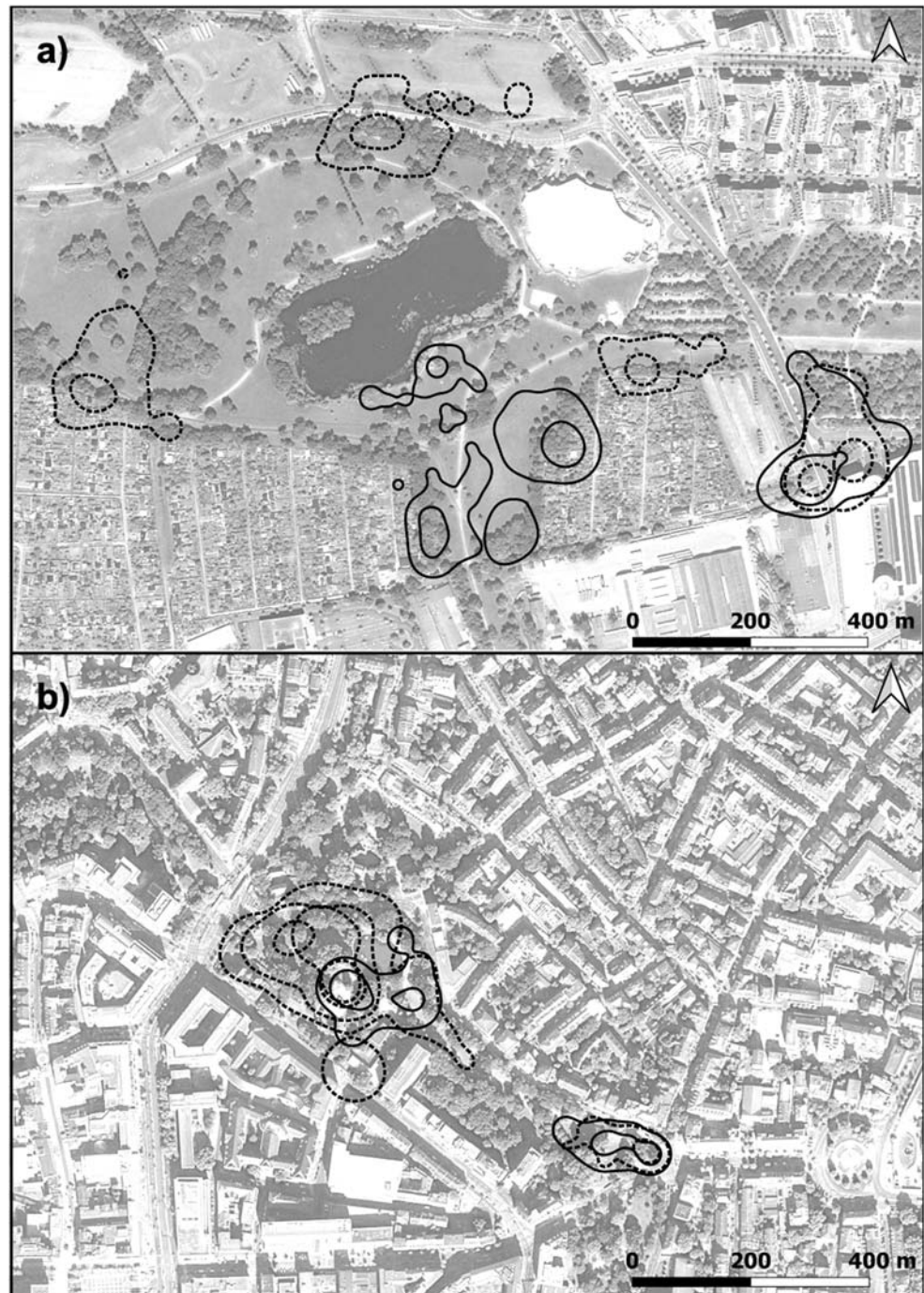
(95–98 sampling points per individual) and 4 males (95–97 sampling points) at our suburban study site, and 3 females (113–117 sampling points) and 2 males in the city center (114 and 115 sampling points; see Table 1). From the remaining collared individuals, we could not collect sufficient location fixes for meaningful statistical analyses. This was due either to the death of the tracked individual (1 case) or the premature loss of the radio collar (3 cases). Prior to data analysis, we tested for site fidelity in conjunction with home range

asymptote exploration, which was apparent for 12 out of 13 animals, while one individual (ID number 3; Table 1) did not show a clear pattern of site fidelity. We analyzed the data with and without this particular individual, but the results were qualitatively similar, demonstrating the robustness of our analyses. We therefore decided to base our subsequent calculations on home range sizes on all 13 animals.

As most studies on the ranging behavior of European rabbits provided minimum convex polygon estimates (MCPs),

Table 1 Individual home range sizes (ha) of all focal individuals included in this study. We used 95% and 50% minimum convex polygons (MCPs) as well as 95%, 75%, and 50% kernel density estimators (KDEs) as proxies for home range dimensions

Focal individual's ID	Sex	MCPs (ha)		KDEs (ha)			Number of location fixes
		95%	50%	95%	75%	50%	
(a) Suburban study site (*Rebstockpark*)							
1	Male	0.75	0.02	1.27	0.48	0.18	97
2	Male	0.53	0.21	1.22	0.55	0.24	95
3	Female	0.65	0.02	1.21	0.45	0.15	97
4	Female	0.95	0.11	1.63	0.73	0.28	91
5	Female	0.65	0.07	1.22	0.39	0.17	97
6	Male	0.43	0.07	0.80	0.29	0.14	96
7	Male	0.34	0.01	0.45	0.09	0.04	95
8	Female	0.35	0.03	0..62	0.24	0.09	98
(b) Urban study site (*Friedberger Anlage*)							
9	Female	0.52	0.09	0.99	0.44	0.21	117
10	Male	0.20	0.10	0.57	0.28	0.14	115
11	Male	1.96	0.27	3.10	1.14	0.52	114
12	Female	0.13	0.04	0.40	0.13	0.05	113
13	Female	0.64	0.31	1.35	0.66	0.30	117

we decided to calculate the same proxy of individuals' home range dimensions using the R package *adehabitatHR* (Kenward 1990; Nilsen et al. 2008; Calenge 2006). However, to ensure comparability of our data to future studies, we also calculated kernel-based home range estimators (KDEs) using the reference bandwidth (Worton 1989; Signer and Balkenhol 2015), applying point KDEs and fixed kernels. As the home range sizes were not normally distributed, we used non-parametric Mann-Whitney U tests in R (version 3.4.4) to test whether home range dimensions might differ between both study sites or between sexes.

Results

We found mean 95% minimum convex polygons (MCPs)—based on data of both study sites combined—to be smaller than ever reported before for our study species, covering 0.50 ± 0.13 ha (mean $\pm$ SE; $n = 13$). Mann-Whitney U tests detected no significant differences in 95% and 50% MCPs as well as 95% and 50% KDEs between our two study sites (Table 2; Fig. 2). Also, both MCP and KDE estimates did not differ significantly between male and female focal individuals (Table 2).

At both study sites, we were able to track individuals underground. At the suburban study site, we twice followed one male individual while it was crossing a street underground to switch between interconnected burrow systems during daytime. Using Google maps, we estimated the distance (above ground) between the two nearest burrow entrances of those two burrows to be approximately 30 m.

Discussion

The results of our present study confirm our first prediction that European rabbits in urban and suburban areas used exceedingly small home ranges compared with those reported for rural populations in other study areas. Devillard et al. (2008) reported the smallest 95% MCP home range dimensions observed in rural populations, with mean values ranging between 7333 m^2 (0.733 ha, $n = 24$ individuals) and 6878 m^2 (0.688 ha, $n = 20$) in two rural areas in France with heterogeneous land-use forms. Mean 95% MCPs in our present study were even smaller but did not differ statistically between sites.

We argue that this pattern can be explained, for the most part, by the high level of structural heterogeneity in suburban and urban areas (Ditchkoff et al. 2006; Kowarik 2011) which allows rabbits to find the required resources within a relatively small area (Gibb 1993; Moreno and Villafuerte 1995;

Table 2 Results of Mann-Whitney U tests using 95% and 50% MCPs as well as 95%, 75%, and 50% KDEs as dependent variables. "Study site" (urban vs. suburban) and "sex" were explanatory variables

Home range estimates	Study site		Sex	
	z	P	z	P
95% MCPs	0.732	0.46	0.142	0.886
50% MCPs	-1.763	0.08	0	1
95% KDEs	0.146	0.88	0.143	0.886
75% KDEs	-0.293	0.77	0	1
50% KDEs	-0.878	0.38	0.143	0.886

Devillard et al. 2008). For example, dense park vegetation and anthropogenic structures within urban and suburban areas provide sufficient shelter for rabbits to establish their burrows, while nearby meadows or urban gardens provide ample food. Rabbits in Frankfurt are even fed by humans in front of their burrow entrances (pers. observation).

Gibb (1993) argued that the combination of food biomass per unit area and access to areas suitable for burrow construction primarily determines home range dimensions in *O. cuniculus* (but see Lombardi et al. 2003, 2007). Agriculturally transformed areas in Central Europe are becoming less structurally diverse, with only few remaining stretches of bushy vegetation remaining in which rabbits can construct burrows (Devillard et al. 2008). Daniels et al. (2003) compared the ranging behavior of rural rabbit populations in Scotland between two sites that differed in land use. If sufficient food is available, rabbits feed on herbs or agricultural crops, while during winter months, they tend to feed on grass and tree bark (Lombardi et al. 2007). At the study site where land-use forms were more suitable to meet those requirements and where sufficient shelter was available, Daniels et al. (2003) calculated a mean home range size of 2.1 ha (95% minimum convex polygon (MCP) dimensions) during spring time. In the second study area, where the preferred landscape elements were less available, mean 95% MCP dimensions (5.2 ha) were more than twice as big (see also Lombardi et al. 2007). Likewise, Ullmann et al. (2018) reported for another lagomorph—the European hare (*Lepus europaeus*)—that individuals in structurally impoverished landscapes had larger home ranges when resource variability was greater, while hares in structurally complex landscapes did not enlarge their home ranges as a function of resource variability.

Unlike Devillard et al. (2008), we detected no sex differences in home range sizes, which may indicate that sample sizes were not sufficient to detect such an effect, even though other studies also found no sex differences (Daniels et al. 2003; Moseby et al. 2005; Lombardi et al. 2007). Likewise, it remains unclear if conclusions can be drawn from our observation that home range dimensions did not differ statistically between suburban and urban sites. If this result can be trusted (i.e., if the pattern is not affected by small sample sizes), then it might indicate that habitat fragmentation plays a minor role in determining home range dimensions compared with the aforementioned factors.

Besides equipping more individuals with radio collars in order to compensate 23.5% failure of radio tags (the loss we experienced in our present study), future studies should also follow collared individuals over a longer period of time. This could provide deeper insights into the question of how often rabbits use underground passages to overcome anthropogenic barriers (such as streets) and how often traffic is a cause of death. We observed individuals to avoid daytime traffic by crossing streets during the night (see also Dowding et al.

2010 for hedgehogs, *Erinaceus europaeus*). While we did find rabbit carcasses along streets, in only few cases could we unequivocally identify traffic accidents as the cause of death, precluding a quantitative analysis of those incidences.

It remains unclear at present whether and how predation affects the ranging behavior of urban rabbit populations: although common natural predators of the European rabbit such as red foxes, *Vulpes vulpes* (Gloor 2001); mustelids like *Martes foina* and *Mustela erminea* (Duduś et al. 2014) or birds of prey like kestrels, *Falco tinnunculus* (Kübler et al. 2005); and northern goshawks, *Accipiter gentilis* (Rutz 2006) or sparrowhawks, *Accipiter nisus* (Risch et al. 1996) can reach high densities in cities, their mere presence does not necessarily mean that they exert strong predation on urban rabbit populations. For example, as reported for red foxes (Contesse et al. 2004) or Cooper's hawk (Estes and Mannan 2003), predators in cities sometimes start exploiting other (more abundant) food sources. Nevertheless, for some species, including European rabbits, hunting has been used to manage urban populations.

In conclusion, our study adds to the very limited information on home range dimensions of a medium-sized, herbivorous mammalian species living in an urban environment. Although our sample size was fairly low, we report the lowest home range dimension ever reported for the European rabbit during the reproduction season. In conjunction with our previous studies reporting on increased densities of European rabbits in urban areas in and around the city of Frankfurt am Main (Ziege et al. 2013), our present study highlights the importance of urban ecosystems not only for human recreation but also for the conservation of populations of otherwise declining wildlife species.

Author's contributions MZ designed, led, and coordinated the project, with input from SM, MP, and SW. MZ, SK, and SW collected field data and undertook data analysis. MZ, BH, SK, SM, WU, SW, and MP undertook further data analysis and data interpretation. MZ, SM, BS, and MP drafted the manuscript. All authors contributed to and approved the final manuscript.

Compliance with ethical standards

References

Adkins C, Stott P (1998) Home ranges, movements and habitat associations of red foxes *Vulpes vulpes* in suburban Toronto, Ontario, Canada. J Zool Lond 244:335–346. https://doi.org/10.1111/j.1469-7998.1998.tb00038.x

Arnold JM, Greiser G, Krüger S, Martin I (2016) Status und Entwicklung ausgewählter Wildtierarten in Deutschland. Jahresbericht 2015. Berlin

Brinkhoff T (2016) City population. Population statistics for countries, administrative areas, cities and agglomerations—interactive maps and charts (2015). http://www.citypopulation.de/de/germany/hessen/06412__frankfurt_am_main/. Accessed 08 Dec 2019

Calenge C (2006) The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. Ecol Model 197(3–4):516–519

Contesse P, Hegglin D, Gloor S, Deplazes P (2004) The diet of urban foxes (*Vulpes vulpes*) and the availability of anthropogenic food in the city of Zurich, Switzerland. Mamm Biol 69:81–95

Daniels MJ, Lees JD, Hutchings MR, Greig A (2003) The ranging behaviour and habitat use of rabbits on farmland and their potential role in the epidemiology of paratuberculosis. Vet J 165:248–257. https://doi.org/10.1016/S1090-0233(02)00238-1

Devillard S, Aubineau J, Berger F, Léonard Y, Roobrouck A, Marchandeau S (2008) Home range of the European rabbit (*Oryctolagus cuniculus*) in three contrasting French populations. Mamm Biol 73:128–137. https://doi.org/10.1016/j.mambio.2007.01.003

Ditchkoff SS, Saalfeld ST, Gibson CJ (2006) Animal behavior in urban ecosystems: modifications due to human-induced stress. Urban Ecosyst 9:5–12

Dowding CV, Harris S, Poulton S, Baker PJ (2010) Nocturnal ranging behaviour of urban hedgehogs, *Erinaceus europaeus*, in relation to risk and reward. Anim Behav 80:13–21. https://doi.org/10.1016/j.anbehav.2010.04.007

Duduś L, Zalewski A, Kozioł O, Jakubiec Z, Król N (2014) Habitat selection by two predators in an urban area: the stone marten and red fox in Wrocław (SW Poland). Mamm Biol 79:71–76

Estes W, Mannan R (2003) Feeding behavior of Cooper's hawks at urban and rural nests in southeastern Arizona. Condor 105:107–116

Garrott R, White G (1990) Analysis of wildlife radio-tracking data. Elsevier, p 42

Gibb JA (1993) Sociality, time and space in a sparse population of rabbits (*Oryctolagus cuniculus*). J Zool Lond 229:581–607

Gloor S (2001) The rise of urban fox populations in Switzerland. Mamm Biol 66:155–164

Hutchings MR, Service KM, Harris SE (2002) Is population density correlated with faecal and urine scent marking in European badgers (*Meles meles*) in the UK? Mamm Biol 67:286–293

Jokimäki J, Suhonen J (1998) Distribution and habitat selection of wintering birds in urban environments. Landsc Urban Plan 39:253–263. https://doi.org/10.1016/S0169-2046(97)00089-3

Kenward R (1990) Ranges iv. Software for analysing animal location data. Institute of Terrestrial Ecology

Kolb HH (1991) Use of burrows and movements of wild rabbit (*Oryctolagus cuniculus*) in an area of hill grazing and forestry. J Appl Ecol 28:892–905

Kowarik I (2011) Cities and wilderness. Environ Pollut 159:1974–1983

Kübler S, Kupko S, Zeller U (2005) The kestrel (*Falco tinnunculus* L.) in Berlin: investigation of breeding biology and feeding ecology. J Ornithol 146:271–278. https://doi.org/10.1007/s10336-005-0089-2

Lees AC, Bell DJ (2008) A conservation paradox for the 21st century: the European wild rabbit *Oryctolagus cuniculus*, an invasive alien and an endangered native species. Mamm Rev 38:304–320. https://doi.org/10.1111/j.1365-2907.2008.00116.x

Lombardi L, Fernandez N, Moreno S, Villafuerte R (2003) Habitat-related differences in rabbit (*Oryctolagus cuniculus*) abundance, distribution, and activity. J Mammal 84:26–36

Lombardi L, Fernandez N, Moreno S, Fernández N (2007) Habitat use and spatial behaviour in the European rabbit in three Mediterranean environments. Basic Appl Ecol 8:453–463. https://doi.org/10.1016/j.baae.2006.09.004

McCleery RA, Lopez RR, Silvy NJ, Gallant DL (2008) Fox squirrel survival in urban and rural environments. J Wildl Manag 72:133–137. https://doi.org/10.2193/2007-138

Møller AP (2008) Flight distance of urban birds, predation, and selection for urban life. Behav Ecol Sociobiol 63:63–75

Moreno S, Villafuerte R (1995) Traditional management of scrubland for the conservation of rabbits *Oryctolagus cuniculus* and their predators in Doñana National Park, Spain. Biol Conserv 73:81–85

Moseby KE, De Jong S, Munro N, Pieck A (2005) Home range, activity and habitat use of European rabbits (*Oryctolagus cuniculus*) in arid Australia: implications for control. Wildl Res 32:305–311. https://doi.org/10.1071/WR04013

Niemelä J (1990) Ecology and urban planning. Biodivers Conserv 8:119–131

Nilsen EB, Pedersen S, Linnell JDC (2008) Can minimum convex polygon home ranges be used to draw biologically meaningful conclusions? Ecol Res 23:635–639. https://doi.org/10.1007/s11284-007-0421-9

Partecke J, Van't Hof T, Gwinner E (2004) Differences in the timing of reproduction between urban and forest European blackbirds (*Turdus merula*): result of phenotypic flexibility or genetic differences? Proc R Soc Lond B 271:1995–2001. https://doi.org/10.1098/rspb.2004.2821

Prange S, Gehrt SD, Wiggers EP (2003) Demographic factors contributing to high raccoon densities in urban landscapes. J Wildl Manag 67:324–333

Prange S, Gehrt SD, Wiggers EP (2004) Influences of anthropogenic resources on raccoon (*Procyon lotor*) movements and spatial distribution. J Mammal 85:483–490

Risch M, Dwenger A, Wirth H (1996) Der Sperber (*Accipiter nisus*) als Brutvogel in Hamburg: Bestandsentwicklung und Bruterfolg 1982–1996. Hamburg Avifaun 28:43–57

Rodewald AD, Gehrt SD (2014) Wildlife population dynamics in urban landscapes. In: McCleery RA, Moorman CE, Peterson MN (eds) Urban wildlife conservation - theory and praxis. Springer, New York, pp 117–147

Rutz C (2006) Home range size, habitat use, activity patterns and hunting behaviour of urban-breeding Northern Goshawks *Accipiter gentilis*. Ardea 94:185–202

Ryan AM, Partan SR (2014) Urban wildlife behavior. In: Urban wildlife conservation - theory and praxis. pp 149–173

Šálek M, Drahníková L, Tkadlec E (2015) Changes in home range sizes and population densities of carnivore species along the natural to urban habitat gradient. Mamm Rev 45:1–14. https://doi.org/10.1111/mam.12027

Schley L, Schaul M, Roper TJ (2004) Distribution and population density of badgers *Meles meles* in Luxembourg. Mamm Rev 34:233–240

Shochat E, Warren PS, Faeth SH, McIntyre N, Hope D (2006) From patterns to emerging processes in mechanistic urban ecology. Trends Ecol Evol 21:186–191

Signer J, Balkenhol N (2015) Reproducible home ranges (rhr): a new, user-friendly R package for analyses of wildlife telemetry data. Wildl Soc Bull 39:358–363

Tucker MA, Böhning-Gaese K, Fagan WF, Fryxell JM, van Moorter B, Alberts SC, Ali AH, Allen AM, Attias N, Avgar T, Bartlam-Brooks H, Bayarbaatar B, Belant JL, Bertassoni A, Beyer D, Bidner L, van Beest F, Blake S, Blaum N, Bracis C, Brown D, de Bruyn PJN, Cagnacci F, Calabrese JM, Camilo-Alves C, Chamaillé-Jammes S, Chiaradia A, Davidson SC, Dennis T, DeStefano S, Diefenbach D, Douglas-Hamilton I, Fennessy J, Fichtel C, Fiedler W, Fischer C,

Fischhoff I, Fleming CH, Ford AT, Fritz SA, Gehr B, Goheen JR, Gurarie E, Hebblewhite M, Heurich M, Hewison AJM, Hof C, Hurme E, Isbell LA, Janssen R, Jeltsch F, Kaczensky P, Kane A, Kappeler PM, Kauffman M, Kays R, Kimuyu D, Koch F, Kranstauber B, LaPoint S, Leimgruber P, Linnell JDC, López-López P, Markham AC, Mattisson J, Medici EP, Mellone U, Merrill E, de Miranda Mourão G, Morato RG, Morellet N, Morrison TA, Díaz-Muñoz SL, Mysterud A, Nandintsetseg D, Nathan R, Niamir A, Odden J, O'Hara RB, Oliveira-Santos LGR, Olson KA, Patterson BD, Cunha de Paula R, Pedrotti L, Reineking B, Rimmler M, Rogers TL, Rolandsen CM, Rosenberry CS, Rubenstein DI, Safi K, Saïd S, Sapir N, Sawyer H, Schmidt NM, Selva N, Sergiel A, Shiilegdamba E, Silva JP, Singh N, Solberg EJ, Spiegel O, Strand O, Sundaresan S, Ullmann W, Voigt U, Wall J, Wattles D, Wikelski M, Wilmers CC, Wilson JW, Wittemyer G, Zięba F, Zwijacz-Kozica T, Mueller T (2018) Moving in the Anthropocene: global reductions in terrestrial mammalian movements. Science 359:466–469. https://doi.org/10.1126/science.aam9712

Ullmann W, Fischer C, Pirhofer-Walzl K, Kramer-Schadt S, Blaum N (2018) Spatiotemporal variability in resources affects herbivore home range formation in structurally contrasting and unpredictable agricultural landscapes. Landsc Ecol 33:1505–1517. https://doi.org/10.1007/s10980-018-0676-2

Venter O, Sanderson EW, Magrach A et al (2016) Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nat Commun 7:12558

Worton BJ (1989) Kernel methods for estimating the utilization distribution in home-range studies. Ecol 70:164–168

Ziege M, Babitsch D, Brix M et al (2013) Anpassungsfähigkeit des Europäischen Wildkaninchens entlang eines rural-urbanen Gradienten. Beiträge zur Jagd- und Wildtierforsch 38:189–199

Ziege M, Brix M, Schulze M et al (2015) From multifamily residences to studio apartments: shifts in burrow structures of European rabbits along a rural-to-urban gradient. J Zool 295:286–293. https://doi.org/10.1111/jzo.12207

Ziege M, Bierbach D, Bischoff S, Brandt AL, Brix M, Greshake B, Merker S, Wenninger S, Wronski T, Plath M (2016) Importance of latrine communication in European rabbits shifts along a rural-to-urban gradient. BMC Ecol 16:29. https://doi.org/10.1186/s12898-016-0083-y

Zollner PA, Smith WP, Brennan LA (2000) Home range use by swamp rabbits (Sylvilagus aquaticus) in a frequently inundated bottomland forest. Am Midl Nat 143:64–69