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„Effects of urbanization on abundance, morphology, body condition and ectoparasite load in small mammal species"

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Content

Abstract

Today more than half of the human population lives in cities. Increasing urbanization leads to a decline in global biodiversity and biotic homogenization. Nevertheless, some animal species can adapt to urban environments by utilizing anthropogenic resources and can even achieve higher population densities in urban landscapes compared to their non-urban conspecifics. This study analyzed differences in species richness, morphology, body condition, ectoparasite load and injury rate of small mammals along a rural-urban gradient using live traps set up in 10 urban greeneries and 10 forest areas in Vienna, Austria between July and October 2020. The extent of urbanization was defined by soil sealing and vegetation cover. A total of 108 individuals were captured belonging to 6 Rodentia and 3 Eulipotyphla species. *Apodemus flavicollis* was the most abundant species in both habitat types. Species richness and abundance were both higher in urban greeneries. Species richness increased along the rural-urban gradient. No significant differences in morphology, body condition or ectoparasite load were found but differences in injury rate were recorded. Injury rate was higher in small mammals trapped in urban greenspaces. While higher species abundance in more urbanized areas may reflect increased food availability resource, reasons for the increased species richness remain very speculative. Urban species might be less affected by natural fluctuations in food supply than their non-urban conspecifics and rely more intensively on anthropogenic resources. Increased population size of *A. flavicollis* and other species associated with tick-borne pathogens in urban environments could become a human health risk. Hence, further studies on spatial distribution patterns of small mammals are recommended.

Keywords: live trapping, small mammals, urbanization, species richness, ectoparasites

Zusammenfassung

Mehr als die Hälfte der Weltbevölkerung lebt heutzutage in Städten. Die verstärkte Urbanisierung hat eine Abnahme der weltweiten Biodiversität und eine biologische Homogenisierung zur Folge. Tierarten können sich unterschiedlich gut an städtische Lebensräume anpassen und Arten, die menschliche Ressourcen besser nutzen können, haben in Städten oft höhere Individuendichten als in den umliegenden Gebieten. In dieser Studie wurden die Unterschiede von Artenreichtum, Morphologie, körperlicher Verfassung, Ektoparasitenbefall und Verletzungshäufigkeit von Kleinsäugern entlang eines Urbanisierungsgradienten untersucht. Zwischen Juli und Oktober 2020 wurden auf 10 innerstädtischen Grünflächen und auf 10 Waldflächen in Wien Lebendfallen aufgestellt. Der Urbanisierungsgrad wurde durch Bodenversiegelung und Vegetationsdichte quantifiziert. Es

wurden 108 Tiere gefangen, die zu 6 Nagetier- und 3 Insektenfresserarten gehörten. *Apodemus flavicollis* wurde in beiden Lebensräumen am häufigsten gefangen. Der Artenreichtum stieg mit zunehmendem Urbanisierungsgrad. Es konnten keine signifikanten Unterschiede hinsichtlich Morphologie, körperlicher Verfassung oder Ektoparasitenbefall gefunden werden, jedoch zeigten sich Unterschiede bei der Verletzungshäufigkeit. Diese lag im Wald deutlich über jener in urbanen Grünflächen. Während die höhere Individuendichte in stark urbanen Flächen möglicherweise das erhöhte Nahrungsangebot wiederspiegelt, sind die Gründe für den erhöhten Artenreichtum weitgehend unklar. Eventuell sind Tierarten in Städten weniger stark von natürlichen Schwankungen in der Nahrungsverfügbarkeit betroffen. Die höhere Populationsgröße und Verbreitung von *A. flavicollis* und anderer Arten, die in Verbindung mit krankheitsübertragenden Zecken stehen, könnte sich zu einem erhöhten Gesundheitsrisiko für Menschen entwickeln. In diesem Zusammenhang werden weitere Arbeiten über die Verbreitungsmuster von Kleinsäugern empfohlen.

Introduction

Since 1950, the world population has nearly tripled from 2.5 billion to 7.7 billion humans in 2019 (United Nations 2019). In the same period, the percentage of the urban population has increased from 30 to 55 % (United Nations 2018). The population of Vienna increased by about 18 % over the last 70 years to 1.9 million inhabitants (Stadt Wien 2020). A growing population necessitates urban development, which results in a higher housing density as well as increased land consumption. The ongoing urbanization process leads to an increasing dominance of artificial structures and sealed surfaces (Shochat et al. 2006). This goes hand in hand with a considerable loss of biodiversity and an increasing biotic homogenization, as modern cities are almost exclusively planned, built and maintained to meet human needs (McKinney 2006). With its residential zones, commercial respectively industrial areas, green spaces and local recreational areas, a city represents a highly fragmented and heterogenic environment. As an urban ecosystem, it differs from the natural surroundings in microclimate, hydrology and soil composition and constant human activities generate a high disturbance rate (Alberti 2005).

The effects of urbanization lead not only to a decline in biodiversity, but also represents a driver for adaptation of the remaining populations of native and new non-native species (Johnson & Munshi-South 2017). For example, recent studies have shown differences between urban and non-urban populations of animal species due to genetic (Harris et al. 2016), morphological (Yu et al. 2017) or behavioral adaptations (Ellington & Gehrt 2019) to urban environments. These adaptations have enabled some species to attain population densities far above those of their non-urban conspecifics. Prominent examples and well known to every city-dweller are the domestic form of the rock pigeon (*Columba livia*) and the Norway rat (*Rattus norvegicus*), which both benefit from the availability of anthropogenic food sources and shelters. Beside feral dogs and cats, also non-domestic carnivores have managed to adapt to urban habitats (Bateman & Fleming 2012). Due to their adaptability and through introduction to new continents by humans, red foxes (*Vulpes Vulpes*) have established the largest distribution of any terrestrial carnivore (Shipper et al. 2008). As in the examples mentioned above, urbanized red foxes tend to reach higher populations densities when compared to their non-urban counterparts (Iossa et al. 2010). Another possible effect of urbanization is the increase of individual body size shown in lizards (Putman & Tippie 2020).

The Norway rat is only one of many small mammal species that have adapted to urban landscapes. While the house mouse (*Mus musculus*) mainly inhabits buildings and is considered an urban exploiter, other species utilize anthropogenic food sources, but still rely on natural resources (urban adapters) (McKinney 2002, 2006). Typically, species richness

declines from suburban areas to the city center. Increasing surface cover and housing density reduce vegetation structure and cover resulting in an increased exposure to domestic or urbanized predators (Dickman 1987, Dickman & Doncaster 1987). The habitat preferences and distributional patterns of rodents and species of the predominately insectivorous order Eulipotyphla have been studied in Central European cities to investigate the adaptive rate of small mammals to urban landscapes (Frynta et al. 1994, Łopucki et al. 2013, Mitter et al. 2014, Klimant et al. 2017). More generalist species find potential shelter and food sources in forest fragments or newly created greenspaces within the urban environment and additionally can exploit anthropogenic food supplies in the surrounding areas (McKinney 2002).

With higher population densities of the adapted species within the remaining urban vegetation areas, there is also an increased probability of direct or indirect contact between wild animals and humans, respectively their pets. Red foxes inhabiting European towns and cities represent a potential health risk to humans, since they are hosts for several parasites (Dwużnik-Szarek & Bajer 2018). Red foxes may transmit Scabies (a group of infectious diseases) caused by mites (*Sarcoptes scabiei*). Furthermore, they serve as hosts for the Cyclophyllid tapeworm (*Echinococcus multilocularis*), which uses rodents as intermediate hosts and is also invasive to humans (Knapp et al. 2016). Studies in rural areas have indicated that species-poor and mice dominated communities could be a transmission vector of zoonotic diseases such as Lyme disease (Ostfeld & Keesing 2000, LoGiudice et al. 2003).

This study is intended to investigate (1) differences in species richness of small mammals between urban and non-urban habitats hypothesizing a decline in biodiversity along the rural-urban gradient, defined by the degree of imperviousness (sealed soil) within the city boundaries of Vienna, Austria. Furthermore, urbanization effects on (2) morphology, (3) body condition, (4) ectoparasite load and (5) injury rate in small mammal populations shall be studied and compared with non-urban populations.

Material and Methods

Study sites

Live trapping of small mammals was conducted in 10 parks or greeneries in the metropolitan area of Vienna, Austria and in 10 forest areas in the western outskirts of the city, which are part of the biosphere reserve Wienerwald dominated by Asperulo-Fagetum beech forests. Owners of the forested areas are the city of Vienna and the Republic of Austria as wells as the forestry administration of the abbey Schottenstift. Only parks and greeneries with a minimum area of 15,000 m² and adequate vegetation cover of trees and understory to hide the live traps were selected. Owner of the parks and greeneries is the city of Vienna with exception of two sites. The Bundesimmobiliengesellschaft m.b.H. owns the area of the Sternwartepark and the Jewish Community (Israelitische Kultusgemeinde Wien) owns the Jewish cemetery in Währing. The two habitat types differing in their extent of urbanization were defined as urban greeneries and woodland (Figure 1, Table 1). All necessary permissions from local authorities and private stakeholders were obtained prior to data collection.
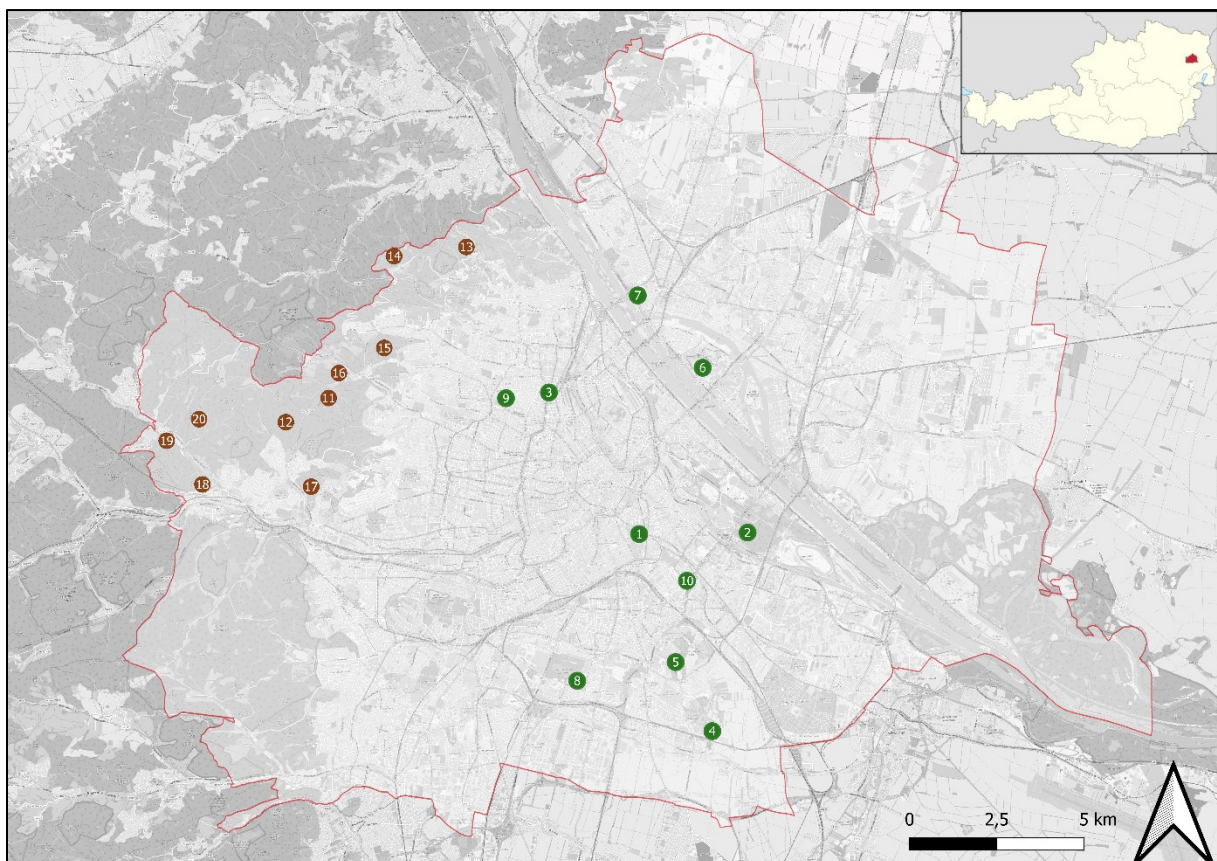

Figure 1: Locations of study sites in the Vienna metropolitan area where live trapping was conducted. Dark green dots show urban greeneries sites, dark brown dots show woodland sites, red line indicates the city boundaries. Site numbers correspond to numbers provided in Table 1.

Table 1: Names, coordinates and elevations of the study sites in the Vienna metropolitan area where live trapping was conducted. Sites 1-10 are urban greeneries, sites 11-20 are woodland areas.

No.	Study site	Geographical coordinates		Elevation (m a.s.l.)
1	Botanical Garden Vienna	48° 11' 41" N	16° 23' 0" E	182
2	Unterer Prater	48° 11' 37" N	16° 25' 31" E	163
3	Jewish cemetery Währing	48° 13' 57" N	16° 21' 6" E	182
4	Kurpark Oberlaa	48° 8' 35" N	16° 24' 26" E	195
5	Laaer Wald	48° 9' 41" N	16° 23' 41" E	250
6	Donaupark	48° 14' 12" N	16° 24' 42" E	170
7	Floridsdorfer Aupark	48° 15' 23" N	16° 23' 17" E	163
8	Wienerberg	48° 9' 29" N	16° 21' 23" E	209
9	Sternwartepark	48° 13' 54" N	16° 20' 6" E	224
10	(former) St. Marx cemetery	48° 10' 55" N	16° 24' 3" E	187
11	Schottenforst Site 1	48° 14' 4" N	16° 16' 0" E	336
12	Schottenforst Site 2	48° 13' 44" N	16° 14' 59" E	322
13	Cobenzl/Haindersbrunn	48° 16' 17" N	16° 19' 23" E	398
14	Hermannskogel	48° 16' 12" N	16° 17' 42" E	470
15	Dorotheer Wald	48° 14' 47" N	16° 17' 21" E	392
16	Kreuzbühel	48° 14' 26" N	16° 16' 16" E	312
17	Area near Steinböckgasse	48° 12' 43" N	16° 15' 29" E	292
18	Laudonscher Wald	48° 12' 50" N	16° 12' 58" E	290
19	Augustiner Wald	48° 13' 32" N	16° 12' 12" E	331
20	Area near Safranwiese	48° 13' 51" N	16° 12' 58" E	330

Trapping methods

The study took place between July and October 2020. Two types of live traps were used: 10 seesaw traps and 10 Sherman folding traps. The seesaw traps (measurements 17 x 7 x 5 cm; with wooden walls and bottom and mesh wire roof; sold by Ehlert & Partner GbR, Germany) used a trigger weight of 5 g. The Sherman folding traps' (measurements 11.2 x 11 x 33 cm; aluminum; sold by Tevigo GmbH, Germany) trigger weight was unknown (at most 29 g). The two types of traps were placed alternately with 10 m spacing. In the forest areas traps were set in 2 rows with 10 m spacing between the rows (a 2 x 10 trapping grid). Since this was not always possible in urban greeneries due to large obstacles or high-density understory vegetation, at some sites traps were placed in one long U-shaped transect avoiding the unsuitable terrain but with the same inter-trap spacing. The live traps were exposed to small rodents for 72 h per trapping site and inspected every 12 h, in the early morning hours and in the evening hours. For each trap, a picture of the surrounding vegetation and a skyward facing shot was taken, to evaluate the vegetation cover above the trap. After the final inspection, traps were recollected and then cleaned before being exposed at the next trapping site. The resulting number of trapping units for all 20 sites was 2,400 (inspections). GPS-coordinates were recorded for every trapping site.

Commercial peanut butter and dried mealworms (MultiFit Tiernahrungs GmbH) were used for baiting rodents and insectivores, respectively. In addition, cotton and cotton pads served as nesting material and enrichment for trapped animals. All captured animals were transferred to a transparent plastic bag and then photographed. The animals were identified to sex and species. Furthermore, body weight (to the nearest 1 g), head to tail length, tail length (both to the nearest 1 mm), ear length and hind foot length (both to the nearest 0.5 mm) were measured (Jenrich et al. 2010). Subsequently, animals were examined for ectoparasites and possible injuries. Present ticks and other ectoparasites were counted for measuring the ectoparasite load. In case of an injury, the affected body part was noted and additional pictures were taken. Examined animals were marked on tail and back (above tailhead) with a white paint stick in order to avoid double counting before being released at the side of capture.

Data analysis

Extent of urbanization

A map showing the respective trapping area for all sites was created with QGIS (QGIS.org, 2020). Data of impervious sealed soil were accessed from Copernicus Land Monitoring Service (Layer: IMD 2015 E40N20, resolution: 20x20 m squares) to measure the extent of urbanization. Each square value ranged from 1 to 100 % of soil sealing. A buffer zone of 200 m was inserted around each trapping area and the QGIS plugin "RasterStats" was used to calculate the mean value of all squares within the respective buffer zone. Additionally, the skyward pictures of the traps were edited with the editing program ImageJ (Schneider et al. 2012) to calculate the respective vegetation cover in % and then the mean vegetation cover for every site was calculated.

Body condition

For the most abundant species *Apodemus flavicollis*, body condition of individuals was defined as the residuals of a linear regression of the relationship between head to tail length and body mass (Figure S1). Visible pregnant female individuals were exempt from this part of analysis.

Statistics

Differences of average extent of soil sealing and vegetation cover as well as standard deviation (SD) of vegetation cover between the two habitat types urban greeneries and woodland were tested with Mann-Whitney U test, since all variables were not normally distributed (soiling sealing: $U=0.76375$, $p=0.0003$; vegetation cover: $U=0.45894$, $p<0.0001$; SD vegetation cover: $U=0.41376$, $p<0.0001$).

A generalized linear model (GLM; with Poisson distribution and log-link function) was used to test for effects of the extent of soil sealing (within 200 m buffer zone around traps), mean vegetation cover and SD of the vegetation cover on species richness of the study sites. Further, generalized linear mixed models (GLMM) were calculated to test for effects of habitat type (forest versus urban greeneries) on body condition, head to tail length and number of ticks (ectoparasite load) of *Apodemus flavicollis* individuals. All GLMMs were calculated using a normal distribution and a logit-link function. Sex and day of the year were considered as co-variables, site ID was included as random factor.

A Chi square test was used to test differences in injury frequencies of *Apodemus* individuals between the two habitat types. Applied programs were R statistics (R Core Team 2021) and IBM SPSS Statistics 27.

Results

Extent of urbanization

Significant differences between urban greeneries and woodland are indicated by calculated Mann-Whitney U test for soil sealing (U=2, p=0.0002) as well as average vegetation cover (U=16, p=0.0113). Soil sealing around traps was higher in urban greenspaces (Figure 2), vegetation cover proved being higher at woodland sites (Figure 3). The SD of the vegetation cover showed no significant differences between the habitat types (U=47, p=0.8501).
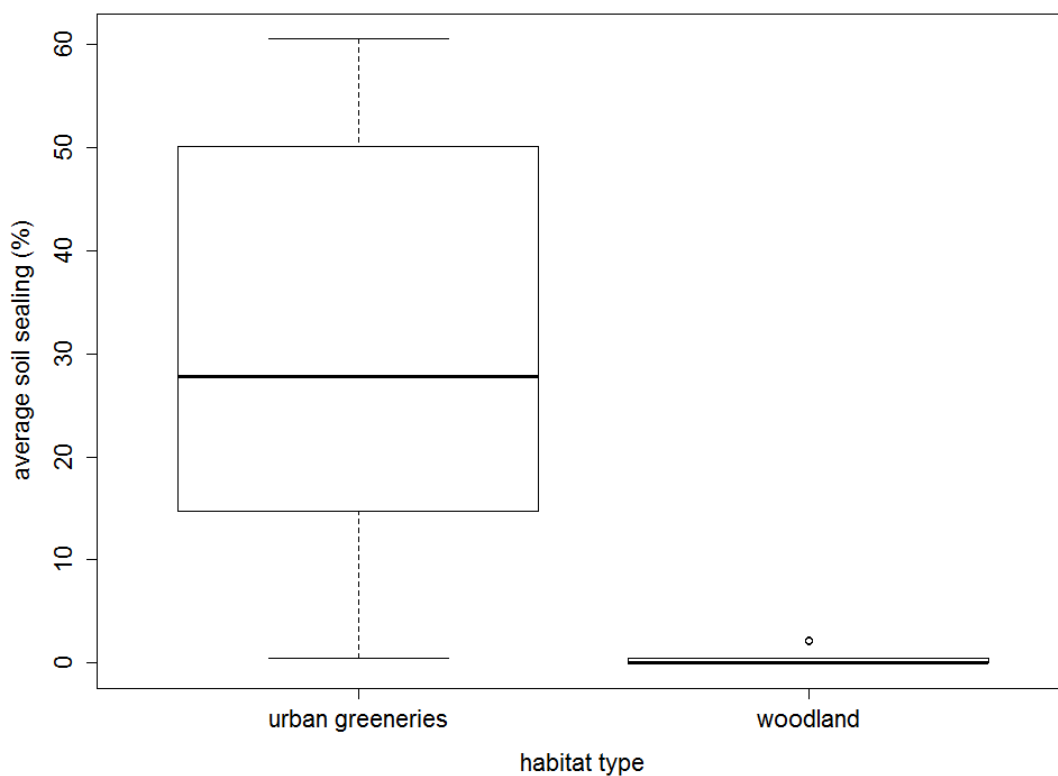
Figure 2: Average soil sealing (%), ± SE (box) and SD (whiskers) of the two habitat types: urban greeneries and woodland. Outliers are indicated as small circles.
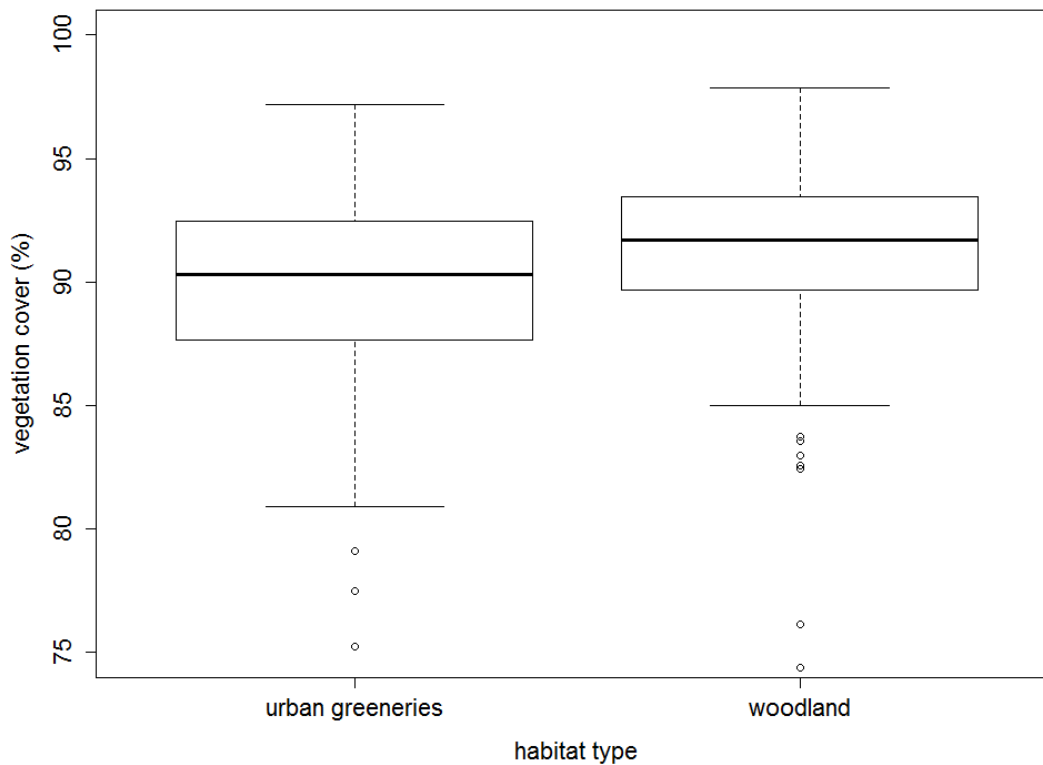
Figure 3: Average vegetation cover (%), ± SE (box) and SD (whiskers) of the two habitat types: urban greeneries and woodland. For better clearness only cover values as of 75 % are shown. Not shown are 8 outliers in urban greeneries. Outliers are indicated as small circles. Raw data of missing outliers is shown in Table S1b (Supplementary material).

Species richness, composition and abundance

In total, 108 animals were recorded plus 12 recaptures resulting in 120 catches. The total number of 120 catches out of 2,400 trapping units resulted in an average trapping success rate of 5 %. Trapping success rate differed between the two habitat types. Average trapping success rate in urban greeneries was 7.75 %, while in woodland the rate was 2.25 %. Overall, 9 species were identified belonging to 6 genera, including 6 rodent species (Rodentia) and 3 insectivores (Eulipotyphla). Most individuals (79) belonged to the genus *Apodemus* and *A. flavicollis* was the most abundant species (with 52 trapped individuals). Several individuals of *Apodemus* could not be identified to species level because they were either too young (5 individuals) or escaped during the transfer from the live trap to the plastic bag (4 individuals). Second in abundance were individuals of the genus *Crocidura* (21 individuals) mostly belonging to the species *C. suaveolens* (18 individuals). Other species were only represented by few individuals (*Clethrionomys glareolus*, *Erinaceus roumanicus*) or singletons (*A. uralensis, Cricetus cricetus and Sciurus vulgaris*). In the woodland habitat type 3 species were recorded and in urban greeneries 6 species. Only individuals of *A. flavicollis* and *A. sylvaticus*

were found in both habitat types. *C. glareolus* (2 individuals) was only found in woodland. All other recorded species were only found in urban greeneries (Figure 4).
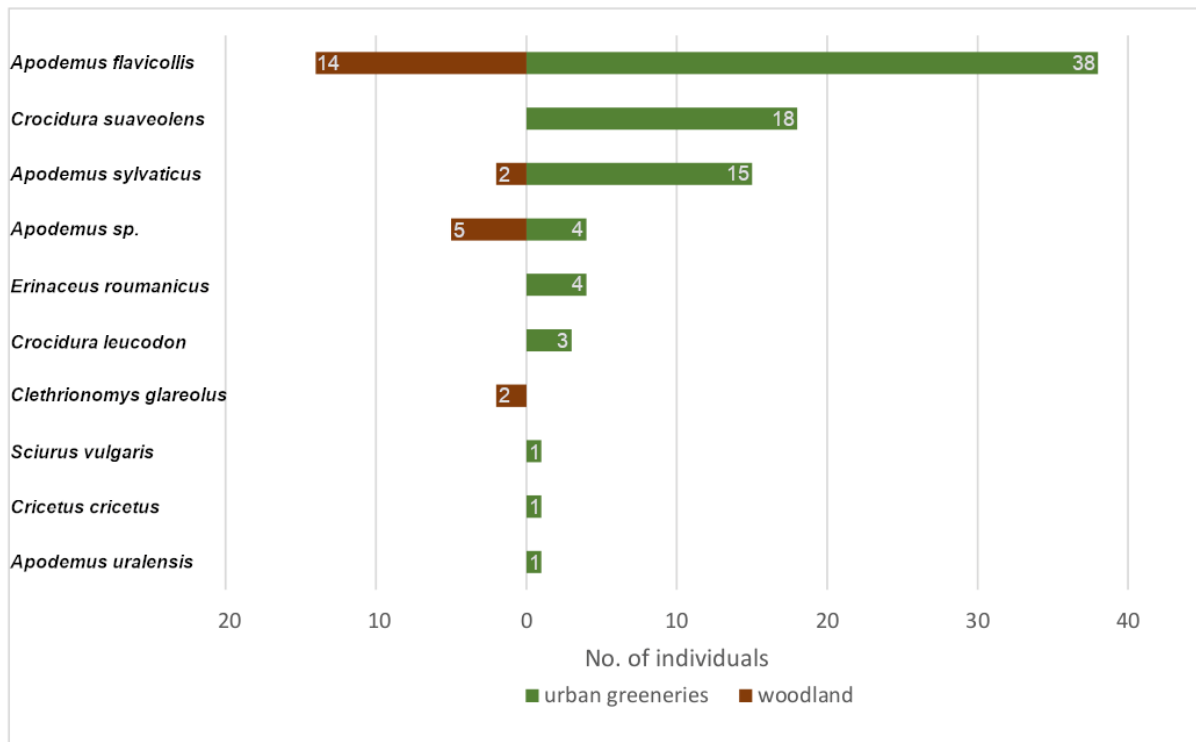
Figure 4: Number of individuals per species captured in the two habitat types. Species are sorted by their total number of trapped individuals.

Species richness along urbanization gradient

The GLM evaluating effects of soil sealing, mean vegetation cover and standard deviation of the vegetation cover on species richness (corrected model: F=6.365, df=3, p=0.005) did indicate a significant effect of soil sealing (F=18.470, df=1, p=0.001), but not of mean vegetation cover (F=1.903, df=1, p=0.187) and SD of vegetation cover (F=0.043, df=1, p=0.838). Species richness increased with increasing soil sealing (Figure 5).
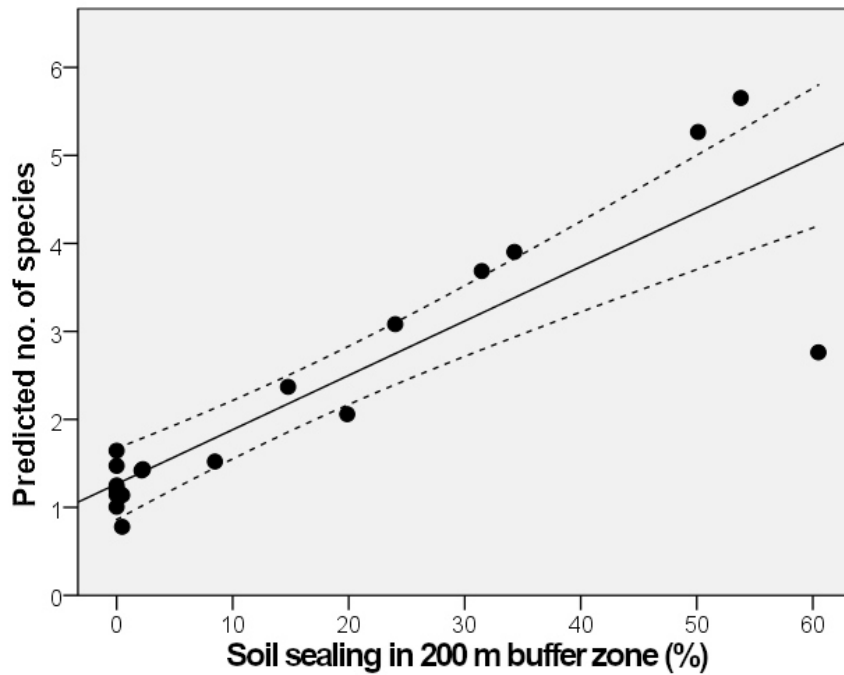
Figure 5: Increase of species richness of study sites along the soil sealing gradient as predicted by a calculated GLM (see text). Broken lines indicate 95% CI of the linear regression (solid line).

Effects of urbanization on body condition, morphology and ectoparasite load

As indicated by the calculated GLMMs (using sex and days of the year as co-variables and site ID as random effect), significant differences of *Apodemus flavicollis* individuals between greeneries (N=48 individuals) and woodland (N=12 individuals) were found neither for body condition (residuals from linear regression of body weight plotted against head-to-tail length; Figure S1; F=1.815, df=2, p=0.157) nor for head to tail length (F=0.719, df=1, p=0.546) and ectoparasite load (F=0.514, df=1, p=0.675). Also, when considering all individuals of the genus *Apodemus*, the calculated GLMM did not indicate a significant difference in ectoparasite load (corrected model: F=0.470, df=1, p=0.627) between individuals of urban greeneries (N=58) and woodland (N=17).

Injury rate in individuals of genus *Apodemus*

Injury frequency did not differ between male and female *Apodemus* individuals (χ^2=0.0545, p=0.8154). However, the injury frequencies of individuals differed significantly between the two habitat types (χ^2=4.9701, p=0.0258). Individuals in woodland habitat (N=17) were more often injured than their conspecifics in urban greeneries (N=58; Figure 6). In urban greeneries 29 % (17 individuals) and in woodland about 59 % (10 individuals) of all trapped *Apodemus* individuals were injured.
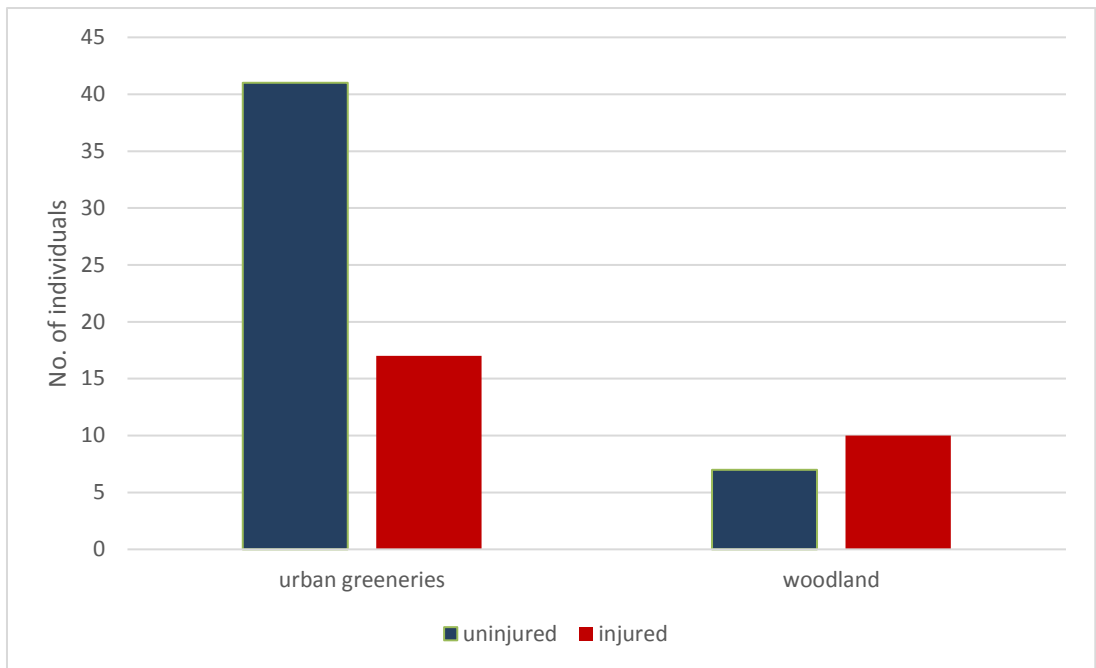
Figure 6: Recorded injury frequencies of captured *Apodemus* individuals in the two habitat types.

Discussion

Species richness, composition and abundance

Habitat quality is an important factor influencing the reproductive success of an individual and thus animal distribution is not random (McLoughlin et al. 2006). Besides habitat properties, periodic events like mast-seeding affect the population density and consequently the distribution patterns of various rodent species (Schnurr et al. 2002). Population densities of rodents increase in the year after a mast-seeding event followed by a decline in the intermediate period. Rodents in urban environments can also profit from increased seedling production during mast-seeding events. But contrary to their rural conspecifics, urban populations have easier access to additional anthropogenic food sources due to their higher proximity to human settlements. Therefore, urban environments can provide constant food supplies for a species' population. Such populations could become less dependent on periodic accruing mast-seeding events, which are heavily influenced by atmospheric circulation patterns (Ascoli et al. 2017).

In this study, trapping success rate differed prominently between the two habitat types, urban greeneries and woodland. Only about 21 % of the trapped animals were captured in woodland habitats and only 3 species were found there. The woodland of the Wienerwald is less fragmented and has a greater extent than the combined area of urban greeneries in Vienna (Stadt Wien 2020) and thus is the more homogeneous habitat type. High fragmentation and spatial limitation within urban landscapes can result in higher animal population densities and smaller individual territories in the few suitable habitats (Luniak 2004). Due to lower population density in a more homogeneous habitat, the set trapping grids could cover fewer individual territories or individuals traveling through the areas, looking for own territories to establish. To cover larger areas, a more common trapping grid size, e. g. 10 x 10 traps per study site (Harkins et al. 2019) or other trap distribution methods (Klimant et al. 2017) could be applied. For this survey, a larger trapping grid was not feasible due to financial and logistic constraints.

An altered habitat structure often also modifies the availability of resources and can promote behavioral changes (Tuomainen & Candolin 2011). Possible adaptions in exploratory behavior or habituation to anthropogenic food could have influenced the approach of urban individuals to the baited live traps and consequently the trapping success rate in urban greeneries. Though overall lower trapping success rate in woodland habitat, two study sites showed an increased success rate. About 61 % of all recorded woodland individuals were captured in these two areas (Table S3). The woodland of the Wienerwald is more natural and less fragmented than the metropolitan area of the city, but commercial and recreational activities still effect this

environment. Ground-dwelling small mammals can encounter human-made objects, e.g. waste or food residues left by visitors, which results in habituation to anthropogenic resources (Newsome & van Eeden 2017).

Species richness along urbanization gradient

Data analysis showed an increase of species richness along the rural-urban gradient. Due to the low trapping success rate in woodland habitats, the assumption that some present small mammal species could not be detected is expectable. Model predictions showed a peak of species richness around 50-55 % soil sealing and indicated a decline towards 60 %. Large-scale models of changes in surface area, species richness and composition assume however a general decline in species richness towards the core of an urban environment (McKinney 2002). From this viewpoint, including sites in city districts with even higher soil sealing rate in future data collections might be telling.

Although an increase in urbanization is correlated with a decline in biodiversity, associated changes in species richness depend on several variables, e.g. the selected taxonomic group or the extent of urbanization (McKinney 2008). Low or moderate extents of urbanization may not affect biodiversity in small mammals negatively (Racey & Euler 1982, Tikhonova et al. 2006). Depending on type of use, management and anthropogenic disturbance rate, urban parks and greeneries can accommodate high richness of small mammal species (Mahan & O'Connell 2005). Parks (or park sections) and greeneries in urban environments managed extensively and used for passive recreational purposes can represent suitable habitats for several species. Most of the urban study sites in Vienna chosen for live trapping have large areas of vegetation resembling more natural habitats or sections used extensively. As a suggestion for future surveys, urban greeneries managed largely for active recreational purposes (e.g. lawns for sunbathing, playing fields) could be included to study the effects of a higher anthropogenic disturbance rate on small mammal communities.

Apodemus individuals in the two habitat types

The low number of individuals captured in woodland habitats turned out to be challenging during data analysis. Generalist species better cope with habitat fragmentation (Newbold et al. 2014) due to their boarder ecological niches. *Apodemus* species are such generalists and they did occur at most urban study sites and in case of *A. flavicollis* on every site (Table S3). Hence, differences in morphology and body condition between urban greeneries and woodland could

only be tested in *Apodemus flavicollis* due to sufficient numbers of captured individuals in both habitat types. Differences in ectoparasite load and injury rate could be tested in all *Apodemus* individuals due to similar ecological needs between the species. However, results did not indicate significant differences neither in morphology, body condition nor ectoparasite load between individuals of the two habitat types. There are no known recent studies that compare body size traits between urban and non-urban *Apodemus* species. A study from Poland on *Apodemus agrarius* documented a higher body mass of males in urban environments compared to individuals trapped at forest sites (Andrzejewski et al. 1978).

In this study, *Apodemus* individuals showed differences in injury rate between the two sampled habitat types. In this analysis, no differentiation of the injury grade was made, but only the affected body parts were recorded (mostly head and tail injuries). Most wild predators tend to avoid city centers (Bateman & Fleming 2012). Hence, the lower injury rate could be the result of a reduced predation risk. Furthermore, the greater availability of food resources could have modified social behavior resulting in reduced intraspecific competition among urban individuals and a decreased risk of injury caused by aggressive interactions between conspecifics. Reduced intraspecific competition in urban environments was also suggested for some mammalian predators (Bateman & Fleming 2012, Robins et al. 2019). Interspecific competition as another cause of injuries cannot be excluded either. Shochat and colleagues (2006) assume that competition for food among species could rather be increased in urban environments.

Rodents are the main hosts for larvae and nymphs of *Ixodes ricinus*, a common tick in Central and Eastern Europe. Adult individuals of *I. ricinus* tend to feed on larger mammals including humans. Thus, pathogens acquired in earlier development stages can be transmitted interspecifically (Mihalca & Sándor 2013). *A. flavicollis* is known to be such an important reservoir and transmission host for tick-borne pathogens, e.g. tick-borne encephalitis (TBE), which is a viral infection disease (Rosà et al. 2007). *A. flavicollis* individuals were recorded in the urban core of Vilnius, Lithuania (Baranauskas et al. 2005) and the city center of Vienna before (Mitter et al. 2015) and a study in Warsaw, Poland found an increased dispersal of this species across the suburban areas of the city over the last four decades (Lesiński et al. 2020). A similar assumption regarding pathogen transmission was made for the white-footed mouse (*Peromyscus leucopus*), a rodent native to North America. Due to elevated population densities of white-footed mice in high fragmented (forest) habitats in the north-eastern USA, the potential human exposure to Lyme disease has increased (Allan et al. 2003).

Conclusion

Anthropogenic resources can be utilized by rodents and make them more independent from natural fluctuations in food availability. Since TBE and other tick-borne pathogens are transmissible to humans, a spread of urban adapted rodent species like *A. flavicollis* within in urban landscapes could represent a potential health issue. Hence, further studies of the distribution patterns of *A. flavicollis* and other small mammal species associated with zoonoses (Essbauer et al. 2009) could contribute to the assessment and management of human health risks in urban environments.

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Supplementary material

Table S1 a: List of study sites showing mean and standard deviation of vegetation cover for each site; b: List of study sites separated by habitat type showing individual vegetation cover for each trap site (MF=seesaw trap, RF=Sherman folding trap).

a

Name of study site	Habitat type	Mean vegetation cover (%)	Standard deviation (%)
Botanical Garden Vienna	urban greeneries	90.80	6.00
Unterer Prater	urban greeneries	90.73	2.21
Jewish cemetery Währing	urban greeneries	67.61	27.58
Kurpark Oberlaa	urban greeneries	91.06	1.86
Laaer Wald	urban greeneries	86.63	2.96
Donaupark	urban greeneries	90.44	2.95
Floridsdorfer Aupark	urban greeneries	90.65	2.05
Wienerberg	urban greeneries	88.63	5.53
Sternwartepark	urban greeneries	90.72	2.12
(former) St. Marx cemetery	urban greeneries	90.84	2.26
Schottenforst Site 1	woodland	92.50	5.09
Schottenforst Site 2	woodland	93.85	2.66
Cobenzl/Haindersbrunn	woodland	91.20	3.03
Hermannskogel	woodland	90.91	2.80
Dorotheer Wald	woodland	90.05	3.19
Kreuzbühel	woodland	91.15	3.93
Area near Steinböckgasse	woodland	88.56	2.76
Laudonscher Wald	woodland	91.64	1.86
Augustiner Wald	woodland	91.49	2.75
Area near Safranwiese	woodland	91.70	1.56

b

Urban greeneries			Woodland		
Name of study site	Trap No.	Vegetation cover (%)	Name of study site	Trap No.	Vegetation cover (%)
Botanical Garden Vienna	MF01	95.87	Schottenforst Site 1	MF01	93.87
	RF01	90.29		RF01	89.44
	MF02	84.91		MF02	90.02
	RF02	94.24		RF02	94.13
	MF03	89.24		MF03	91.67
	RF03	94.96		RF03	95.55
	MF04	93.58		MF04	94.44
	RF04	89.02		RF04	89.05
	MF05	96.45		MF05	74.40
	RF05	96.53		RF05	97.49
	MF06	90.76		MF06	93.16
	RF06	91.41		RF06	93.75
	MF07	91.01		MF07	96.19
	RF07	85.01		RF07	95.71
	MF08	90.93		MF08	88.13
	RF08	93.89		RF08	96.23
	MF09	97.09		MF09	97.54
	RF09	70.41		RF09	90.60
	MF10	93.10		MF10	94.47
	RF10	87.28		RF10	94.21

Unterer Prater	MF01	93.29	Schottenforst Site 2	MF01	90.80
	RF01	92.26		RF01	94.25
	MF02	93.35		MF02	96.60
	RF02	92.83		RF02	93.17
	MF03	90.66		MF03	93.02
	RF03	91.91		RF03	94.50
	MF04	88.73		MF04	92.79
	RF04	92.48		RF04	93.44
	MF05	92.94		MF05	94.31
	RF05	90.54		RF05	93.75
	MF06	92.76		MF06	92.85
	RF06	93.37		RF06	96.28
	MF07	86.87		MF07	93.86
	RF07	87.01		RF07	94.14
	MF08	89.19		MF08	96.71
	RF08	90.16		RF08	93.59
	MF09	90.05		MF09	85.01
	RF09	90.12		RF09	96.09
	MF10	87.21		MF10	94.05
	RF10	88.95		RF10	97.86
Jewish cemetery Währing	MF01	86.11	Cobenzl/Haindersbrunn	MF01	85.34
	RF01	79.09		RF01	97.15
	MF02	47.57		MF02	91.77
	RF02	53.42		RF02	92.95
	MF03	29.91		MF03	92.32
	RF03	4.70		RF03	89.97
	MF04	59.62		MF04	91.78
	RF04	75.25		RF04	89.22
	MF05	68.96		MF05	90.38
	RF05	71.17		RF05	91.82
	MF06	95.75		MF06	91.95
	RF06	4.63		RF06	88.91
	MF07	93.04		MF07	93.77
	RF07	71.93		RF07	83.55
	MF08	97.17		MF08	93.18
	RF08	68.13		RF08	88.82
	MF09	85.71		MF09	93.18
	RF09	81.27		RF09	92.08
	MF10	96.30		MF10	93.94
	RF10	82.53		RF10	91.87

Kurpark Oberlaa	MF01	93.07	Hermannskogel	MF01	91.50
	RF01	91.40		RF01	85.92
	MF02	91.61		MF02	94.73
	RF02	90.74		RF02	93.98
	MF03	92.84		MF03	93.24
	RF03	92.43		RF03	90.23
	MF04	91.67		MF04	92.10
	RF04	92.66		RF04	92.04
	MF05	90.17		MF05	92.54
	RF05	86.80		RF05	93.20
	MF06	87.55		MF06	93.31
	RF06	90.20		RF06	91.92
	MF07	92.10		MF07	89.24
	RF07	93.11		RF07	85.31
	MF08	92.13		MF08	87.52
	RF08	89.88		RF08	90.98
	MF09	91.07		MF09	94.15
	RF09	93.25		RF09	86.76
	MF10	90.38		MF10	89.52
	RF10	88.21		RF10	89.93
Laaer Wald	MF01	82.13	Dorotheer Wald	MF01	91.90
	RF01	80.92		RF01	85.19
	MF02	89.31		MF02	89.18
	RF02	91.36		RF02	93.28
	MF03	88.47		MF03	91.17
	RF03	87.85		RF03	88.89
	MF04	85.64		MF04	87.21
	RF04	84.51		RF04	91.51
	MF05	88.52		MF05	91.21
	RF05	90.35		RF05	93.98
	MF06	88.34		MF06	91.72
	RF06	86.04		RF06	82.57
	MF07	86.76		MF07	91.78
	RF07	86.85		RF07	86.42
	MF08	91.43		MF08	96.23
	RF08	84.77		RF08	88.13
	MF09	87.07		MF09	89.11
	RF09	83.70		RF09	90.95
	MF10	82.41		MF10	92.19
	RF10	86.08		RF10	88.39

Donaupark	MF01	93.08	Kreuzbühel	MF01	94.45
	RF01	92.15		RF01	93.08
	MF02	84.81		MF02	89.87
	RF02	93.28		RF02	91.76
	MF03	92.46		MF03	90.45
	RF03	88.37		RF03	92.91
	MF04	88.18		MF04	91.56
	RF04	90.27		RF04	95.13
	MF05	86.93		MF05	90.43
	RF05	89.24		RF05	91.60
	MF06	85.99		MF06	93.01
	RF06	86.30		RF06	90.37
	MF07	90.77		MF07	89.98
	RF07	89.64		RF07	93.81
	MF08	92.04		MF08	88.13
	RF08	93.92		RF08	91.59
	MF09	94.80		MF09	93.43
	RF09	92.77		RF09	93.21
	MF10	93.78		MF10	92.10
	RF10	89.97		RF10	76.16
Floridsdorfer Aupark	MF01	88.24	Area near Steinböckgasse	MF01	89.46
	RF01	92.02		RF01	89.14
	MF02	92.94		MF02	92.93
	RF02	93.42		RF02	82.97
	MF03	90.58		MF03	88.76
	RF03	87.02		RF03	88.49
	MF04	90.86		MF04	87.15
	RF04	91.16		RF04	89.67
	MF05	93.84		MF05	90.43
	RF05	88.22		RF05	90.40
	MF06	89.00		MF06	90.01
	RF06	90.07		RF06	89.64
	MF07	88.18		MF07	88.28
	RF07	93.40		RF07	90.10
	MF08	91.77		MF08	90.17
	RF08	90.57		RF08	88.84
	MF09	87.48		MF09	82.43
	RF09	91.74		RF09	91.83
	MF10	91.44		MF10	86.67
	RF10	91.12		RF10	83.75

Wienerberg	MF01	88.26	Laudonscher Wald	MF01	93.47
	RF01	89.29		RF01	93.34
	MF02	89.37		MF02	94.10
	RF02	69.61		RF02	92.87
	MF03	90.61		MF03	95.16
	RF03	92.47		RF03	91.67
	MF04	89.99		MF04	90.70
	RF04	89.81		RF04	89.89
	MF05	77.47		MF05	89.53
	RF05	90.55		RF05	91.92
	MF06	89.70		MF06	89.21
	RF06	90.04		RF06	92.00
	MF07	89.81		MF07	89.72
	RF07	86.60		RF07	89.67
	MF08	90.05		MF08	93.52
	RF08	92.47		RF08	93.74
	MF09	91.64		MF09	91.68
	RF09	93.80		RF09	89.26
	MF10	90.01		MF10	89.62
	RF10	91.06		RF10	91.70
Sternwartepark	MF01	88.38	Augustiner Wald	MF01	92.89
	RF01	92.34		RF01	92.51
	MF02	92.58		MF02	95.51
	RF02	93.17		RF02	89.86
	MF03	93.76		MF03	91.64
	RF03	90.87		RF03	94.46
	MF04	89.07		MF04	88.14
	RF04	92.87		RF04	91.08
	MF05	92.27		MF05	85.50
	RF05	90.60		RF05	89.97
	MF06	87.63		MF06	91.91
	RF06	91.69		RF06	87.18
	MF07	89.87		MF07	88.52
	RF07	87.71		RF07	91.56
	MF08	87.12		MF08	94.97
	RF08	90.77		RF08	89.99
	MF09	91.29		MF09	91.69
	RF09	91.73		RF09	93.73
	MF10	87.75		MF10	94.82
	RF10	92.97		RF10	93.86

(former) St. Marx cemetery	MF01	89.43	Area near Safranwiese	MF01	92.77
	RF01	90.78		RF01	91.11
	MF02	91.52		MF02	91.03
	RF02	91.25		RF02	92.21
	MF03	90.42		MF03	94.12
	RF03	93.90		RF03	89.15
	MF04	92.82		MF04	91.65
	RF04	93.21		RF04	91.77
	MF05	89.37		MF05	90.95
	RF05	90.30		RF05	90.53
	MF06	91.11		MF06	90.34
	RF06	91.10		RF06	89.93
	MF07	93.74		MF07	92.28
	RF07	89.32		RF07	89.98
	MF08	85.27		MF08	92.99
	RF08	89.77		RF08	93.59
	MF09	86.98		MF09	95.45
	RF09	89.71		RF09	90.67
	MF10	92.79		MF10	91.10
	RF10	94.02		RF10	92.40

Table S2: Measured head to tail length, body mass and calculated body condition of 50 individuals of *Apodemus flavicollis* captured in the two habitat types.

Individual No.	Date	Habitat type	Sex	Body condition	Body mass (g)	Head to tail lenght (mm)
1	09/07/2020	urban greeneries	W	12.80	23	68
2	09/07/2020	urban greeneries	M	4.04	26	81
3	10/07/2020	urban greeneries	W	9.80	23	71
4	11/07/2020	urban greeneries	M	-7.91	14	76
5	26/07/2020	urban greeneries	W	-1.08	33	96
6	28/07/2020	urban greeneries	W	3.45	27	83
7	04/08/2020	urban greeneries	W	0.74	18	73
8	04/08/2020	urban greeneries	W	-6.73	29	96
9	05/08/2020	urban greeneries	W	3.57	20	73
10	05/08/2020	urban greeneries	M	-3.43	20	80
11	05/08/2020	urban greeneries	W	8.04	26	77
12	05/08/2020	urban greeneries	M	4.03	9	57
13	06/08/2020	urban greeneries	M	-4.37	25	88
14	12/08/2020	urban greeneries	W	-0.55	27	87
15	13/08/2020	urban greeneries	W	-9.96	26	95
16	14/08/2020	urban greeneries	M	1.80	23	79
17	14/08/2020	urban greeneries	W	-1.73	29	91
18	20/08/2020	urban greeneries	M	2.33	34	94
19	20/08/2020	urban greeneries	M	-1.08	33	96
20	20/08/2020	urban greeneries	M	-4.78	41	111
21	22/08/2020	urban greeneries	M	6.27	29	83
22	28/08/2020	urban greeneries	W	-4.79	24	87
23	29/08/2020	urban greeneries	M	-4.02	21	82
24	29/08/2020	urban greeneries	M	3.09	14	65
25	05/09/2020	urban greeneries	M	-5.14	28	93
26	14/09/2020	urban greeneries	M	-0.02	38	102
27	15/09/2020	urban greeneries	W	3.04	43	106
28	15/09/2020	urban greeneries	W	-0.61	39	104
29	23/09/2020	urban greeneries	M	-2.20	23	83
30	25/09/2020	urban greeneries	W	-0.37	25	84
31	25/09/2020	urban greeneries	W	-1.37	25	85
32	26/09/2020	urban greeneries	M	0.21	24	82
33	26/09/2020	urban greeneries	M	-5.49	15	75
34	26/09/2020	urban greeneries	M	2.57	20	74
35	27/09/2020	urban greeneries	W	-1.55	27	88
36	27/09/2020	urban greeneries	M	2.04	26	83
37	27/09/2020	urban greeneries	W	0.04	26	85
38	27/09/2020	urban greeneries	M	0.74	18	73
39	22/07/2020	woodland	M	1.27	29	88
40	22/07/2020	woodland	W	5.45	27	81
41	22/07/2020	woodland	M	2.04	43	107
42	23/07/2020	woodland	W	6.45	27	80
43	09/08/2020	woodland	W	3.98	21	74
44	15/08/2020	woodland	M	1.39	39	102
45	16/08/2020	woodland	M	-3.25	35	101
46	16/08/2020	woodland	M	3.69	30	87
47	17/08/2020	woodland	M	-1.49	32	95
48	17/08/2020	woodland	W	-6.96	26	92
49	26/08/2020	woodland	W	-8.14	28	96
50	02/09/2020	woodland	M	-5.85	19	81

Table S3: Number of captured individuals per species and study site in the two habitat types. (BOT=botanical garden Vienna, PRA=Unterer Prater, JUE=Jewish cemetery Währing, OBE=Kurpark Oberlaa, LAA=Laaer Wald, DON=Donaupark, FLO=Floridsdorfer Aupark, WIE=Wienerberg, STE=Sternwartepark, MAR=(former) St. Marx cemetery, SOS=Schottenforst Site 1, SWE=Schottenforst Site 2, COB=Cobenzl/Haindersbrunn, HER=Hermannskogel, DOR=Dorotheer Wald, KRE=Kreuzbühel, SBG=Area near Steinböckgasse, LAU=Laudonscher Wald, AUG=Augustiner Wald, SAF=Area near Safranwiese)

| Species	urban greeneries										woodland									
	BOT	PRA	JUE	OBE	LAA	DON	FLO	WIE	STE	MAR	SOS	SWE	COB	HER	DOR	KRE	SBG	LAU	AUG	SAF
Apodemus flavicollis	4	2	7	4	4	3	1	3	1	9	-	5	1	1	5	1	1	-	-	-
Apodemus sylvaticus	2	-	1	-	1	4	-	-	1	5	-	2	-	-	-	-	-	-	-	-
Apodemus uralensis	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Clethrionomys glareolus	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Cricetus cricetus	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Crocidura leucodon	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Crocidura suaveolens	-	-	-	1	-	7	8	-	1	1	-	-	-	-	-	-	-	-	-	-
Erinaceus roumanicus	-	-	-	2	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Sciurus vulgaris	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apodemus sp.	-	-	-	1	1	1	-	1	1	1	1	2	1	-	-	-	-	-	-	1
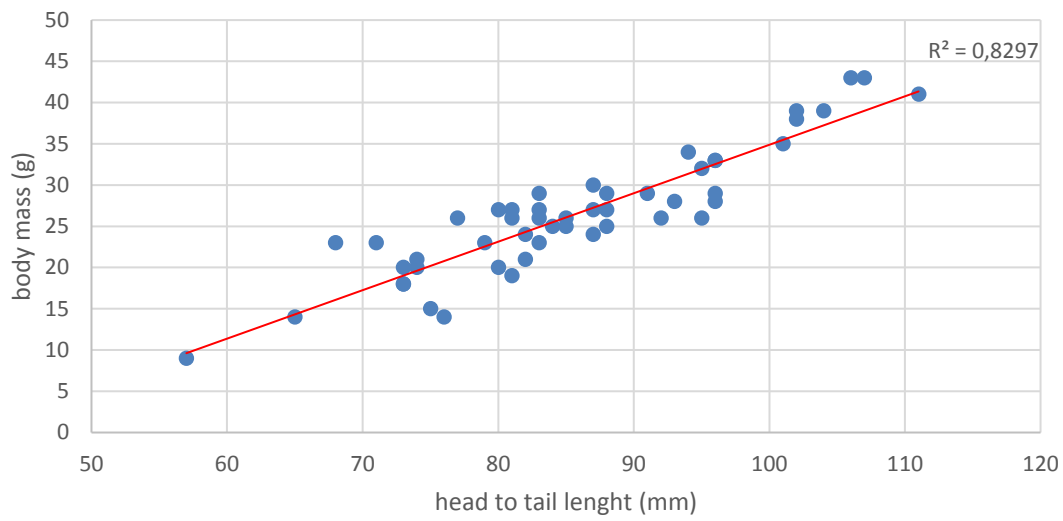
Figure S1: Linear regression of the relationship between head to tail length and body mass of 50 individuals of *Apodemus flavicollis*. Individual body conditions are quantified as residuals. More detailed information is provided in Table S2. Two females had to be excluded due to visible pregnancy.