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Monitoring Urban European Hares (*Lepus europaeus* Pallas) with Citizen Science and a Thermal Spotter

Sussie Pagh [1,*], Lasse Lange Jensen [1], Cino Pertoldi [1,2] and Hanne Lyngholm Larsen [1]

[1] Section of Environmental Biomonitoring, Department of Chemistry and Bioscience, University of Aalborg, 9220 Aalborg, Denmark; lasse@migselv.com (L.L.J.); hannell@bio.aau.dk (H.L.L.)
[2] Aalborg Zoo, 9000 Aalborg, Denmark
* Correspondence: sup@bio.aau.dk

Abstract: Populations of the European hare (*Lepus europaeus* Pallas) have declined in agricultural areas throughout Europe, primarily due to habitat loss caused by the industrialization of agriculture. The growth of cities displaces native habitats, and a decline in hare densities would be expected also in cities; however, several medium-sized mammals thrive in urban areas. In this study, hares in two Danish cities, Aalborg and Aarhus (approx. 145,000 and 300,000 citizens, respectively), were monitored using a combination of citizen science and a thermal spotter. Citizen reports of hares (in all 1874) were highest in the center of the city (26 to 33 locations per km^2). Hare observation densities declined significantly with increasing distance to the center. Breeding hares were recorded in both cities. The thermal spotter proved to be useful to spot hares in the city and it did not draw attention as the spotlights normally used to detect the light reflected from the hares' eyes. Based on the hares spotted at 12 locations where citizens had reported hares, densities of 40.3 (±10.8 SE) hares per km^2 were estimated. The increasing awareness for biodiversity and for not using pesticides in Danish cities allow for wild plants to be established in lawns, which benefits the hares.

Keywords: urban mammal; urban wildlife; urban biodiversity; conservation

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1. Introduction

The native habitat for the European hare (*Lepus europaeus* Pallas), hereafter, the hare, is the open grasslands of Central Europe and Central Asia [1]. Hares most probably became common in Denmark after the extensive deforestation of the country in the Neolithic Age, i.e., 5500 years ago, long after many other native mammals immigrated shortly after the Ice Age (around 11,000 years ago) [2,3]. At the beginning of the 20th century, agricultural areas were ideal habitats for hares, as fields were smaller, and farming was extensive with more weeds in native habitats. Before 1960, up to half a million hares were shot annually in Denmark, but the National hunting game bags gradually decreased, and in recent years, the annual game bag of hares has been less than 40,000 [4]. The decline in the hare populations has occurred throughout Europe, and there is a broad agreement that the decline in the hare population is primarily due to habitat loss, i.e., industrialization of agriculture with increasing field sizes, the removal of field boundaries, and other native habitats in agricultural land [1,5–10]. In Denmark, the hare was red-listed in 2007 as vulnerable (VU) after the national population declined by more than 30% over the years [11]. Since 2018, the hare in Denmark and international is listed as "least concern" (LC).

There are only a few reports of hares in urban areas in Europe. However, these studies, e.g., in Denmark and Sweden (also, mountain hare (*L. timidus* L.) and rabbit (*Oryctolagus*

cuniculus L.), in the Czech Republic and Austria have witnessed that hares are living in more European cities [12–14].

Hares are primarily herbivorous and prefer weeds, grasses, and various crop types while avoiding cereals [1,15]. This preference is particularly relevant during the summer when crops grow tall, potentially limiting food availability in agricultural areas, whereas urban areas may provide a more stable food supply year-round.

Especially in the United Kingdom, other medium-sized mammals, including the non-native Eastern gray squirrel (*Scirus carolinensis* Gmelin), European hedgehog (*Erinaceus europaeus* L.), red fox (*Vulpes vulpes* L.), and European badger (*Meles meles* L.), are known to thrive in urban habitats [16–22]. Foxes and gray squirrels are considered to be the best adapted with the most suitable habitats in central London, while hedgehogs and badgers prefer suburban and rural areas, respectively [20]. Cities have become greener both in Denmark and other parts of the world to promote human well-being, and at the same time, these green areas attract wildlife [12,20,23,24]. In modern times, hares are known to have been present in Aarhus, Denmark [14]. In the former study [14] of hares in Aarhus in 2018, the density of hares, based on line transects, was estimated to be 8 hares per km^2 when excluding buildings [14].

Monitoring hares and other mammals in agricultural areas and other more native habitats has previously been conducted using wildlife cameras, spotlight counts, or, more recently, drones fitted with cameras have been used [25]. Such monitoring data are crucial to support sound conservation planning for hares and other species. However, monitoring hares in cities poses challenges, as wildlife cameras are only allowed on private property, drones are not legal to fly in cities without special permission, and strong spotlights may cause unnecessary concern among city residents [14,25].

As cities may have a conservation significance for wildlife that has been displaced from the intensively cultivated farmland, it is of great interest to develop methods to monitor hares and other wildlife in cities and to gain knowledge about their preferred habitats, reproduction, and mortality.

The aim of this study is to test two methods for monitoring hares in the urban environment and to identify locations preferred by the hares within the cities of Aarhus and Aalborg, Denmark. We believe that our evaluation of the citizen science method and a novel monitoring method will be beneficial for future monitoring programs for hares and other wildlife in the urban environment.

2. Materials and Methods

2.1. Citizens Science

To contact citizens in Aalborg and Aarhus an article describing a citizen science study of hares was published in a nationwide newspaper on 14 July 2022. In this article, the citizens of the two Danish cities, the second and fourth largest in Denmark, were asked to write an e-mail to a scientist at the University of Aalborg and to report their hare sightings. The study was carried out in Aarhus, approx. 300,000 citizens, and Aalborg approx. 145,000. Through the announcements, the citizens were asked to report hare sightings within 100 m of buildings, together with the date, time of day, and location provided as either an address or GPS coordinates. Additionally, they were asked to indicate whether the hare was a leveret or an adult. If possible, citizens were asked to send a photo of the hare. The media coverage of the announcement of the hares spread to at least 25 different media outlets, both newspapers and radio during July 2022. We assumed hares to be so characteristic that they would not be confused with other mammals, as wild rabbits are not present in the area. Citizens were not trained or asked to report hare sightings repeatedly; they were asked

to report the localities where they had observed hares. All citizens who sent information received a response and thanks from the researcher.

2.2. Survey with Thermal Spotter

To test the usability of a Pulsar Axion XM30S Pro Thermal Spotter, LT-06326, Vilnius Lithuania (resolution 320 × 240 pixels and digital 4.5–18 zoom, detection range 1300 m), 12 locations that covered different city habitats and had been reported as hare locations by the citizens in Aalborg were visited. At these locations, hares were spotted and video recorded with the thermal spotter. A thermal camera creates an image of an object by using thermography, which allows the user to see variations in temperature, e.g., a warm-bodied animal. For two nights, one in May and one in September 2023, the areas of the 12 locations were scanned, and the density of hares per km^2 was estimated from the number of hares spotted and the area covered.

2.3. Data Analysis

All addresses of hare observations were transformed into GPS coordinates. In cases where multiple reports were from the same location, only the report with the largest number of hares was retained, and all other reports from that location were removed. A heat map of hare recordings from citizens of each city was created with eight circles, starting from the city center (the railway station) and outwards with a distance between circles of 1 km. The areas covered with different location types were digitized, and areas with apartment blocks and private households with gardens were calculated using QGIS, based on the Danish Data Supply, Creative Commons Attribution 4.0 International [26].

The number of reported locations with hares per km^2 (density of hares) at different distances from the two cities (Aalborg and Aarhus) centers was tested for correlations with a linear and polynomial regression analysis to detect a trend in the density of hares from the city center to the periphery. The correlations between the cumulative percentile curves of the time at which the hares were observed in the different localities (apartment areas, private gardens, city centers, port areas, and commercial districts) were calculated in order to test if there were any biases in the times at which the hares were observed in the different localities. A Chi-square test was used to compare the frequency of double recordings (the same address within 24 h) of hares. The significance level was $p < 0.05$. The statistical software used to conduct the analyses was Past version 4.03 [27].

3. Results

3.1. Citizens Science in Aalborg and Aarhus

3.1.1. Number of Reports

In total, 1874 hare sightings were reported by citizens in Aarhus and Aalborg; of these, 1626 were reported from July to August 2022, at different addresses within 24 h. Of these, 629 hares were seen at unique locations in Aarhus and at 659 locations in Aalborg. Of the hares spotted in Aalborg, 64 were reported as leverets, and 80 were reported as leverets in Aarhus (Figure A1). Hence, 10% and 13% of the hares in Aalborg and Aarhus were leverets, respectively.

In both Aarhus and Aalborg, hares were reported from many different location types such as apartment blocks, private gardens, cemeteries, parks, and lawns around hospitals, universities, and commercial districts (Table 1).

Table 1. Localities from where hares were reported: Aarhus and Aalborg.

Type of Location	Aarhus *n* = 629	Aalborg *n* = 659
Apartments areas	309	257
Private gardens	137	205
Parks	55	19
City centers	35	39
Port areas	23	56
Commercial districts	23	49
University parks	11	10
Hospital lawns	11	2
Cemeteries	11	7
Allotment	10	10
Holiday home area	1	0
Field	2	0
Construction site	1	0
Salt meadow	0	1
Football pitch	0	2
Calk mining pit	0	1
City wood	0	1

3.1.2. Densities of Hares in Different City Zones

In both Aarhus and Aalborg, most observations with hares were from the central part of the city. Within 1 km from the city center the density of locations with hare observations were 33 and 26 per km^2, for Aalborg and Aarhus, respectively. The density of reported hares decreased gradually with distance from the city center and outwards (Figure 1).

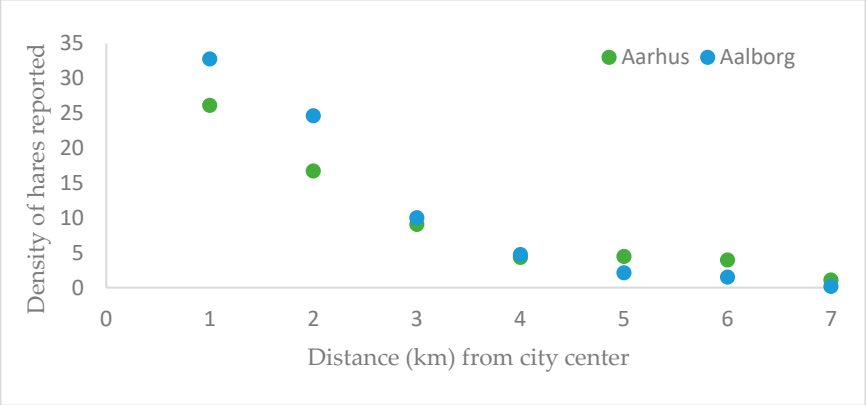

Figure 1. The number of reported locations with hares per km^2 in different distances to the city center (Table A1).

The regression analyses, including linear and polynomial regression, showed a significant declining trend in the density of detected hares from the city center to the periphery (Aalborg: Linear regression: $Y = -5.43 + 32.57$, $R^2 = 0.84$, $p < 0.01$; Polynomial regression: $Y = 1.30 \times 2 - 1585x + 48.2$, $R^2 = 0.98$, $p < 0.001$; Aarhus: Linear regression: $Y = -3.76 + 24.41$, $R^2 = 0.82$, $p < 0.01$; Polynomial regression: $Y = 0.93 \times 2 - 11.21x + 35.59$, $R^2 = 0.97$, $p < 0.001$).

The density of reported locations with hares was higher in areas with apartment blocks than in areas with private gardens. In the area between one and two km from the city center, where both apartment blocks and private gardens occur, the locations reported with hares were 5.4 times higher in apartment blocks than in private gardens in Aalborg and 4.7 times higher in Aarhus (Figure 2a,b).

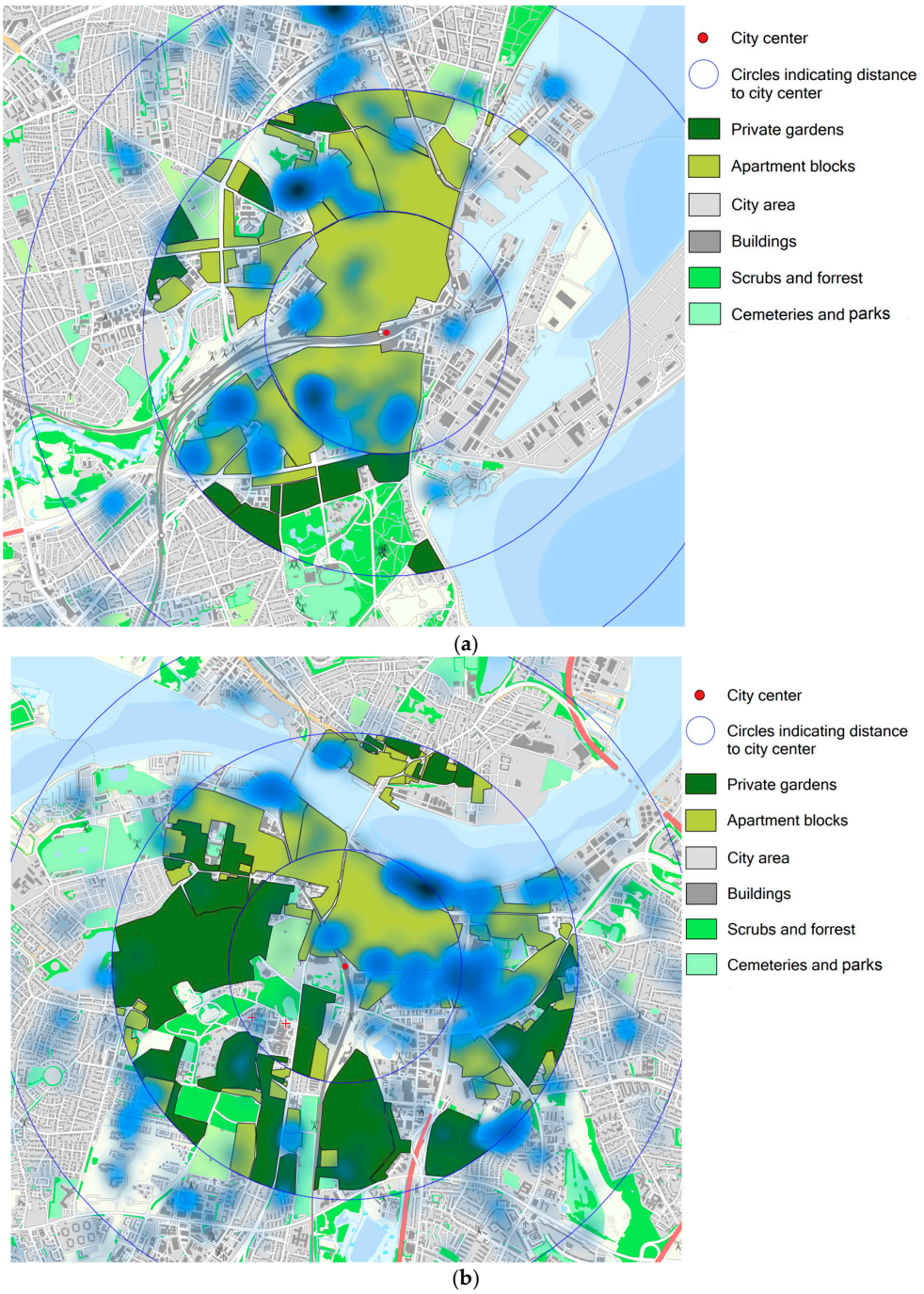

Figure 2. (**a**). Heat map of hare reports (blue) by citizens of Aarhus in the three inner circles of the city. (**b**). Heat map of hare reports (blue) by citizens of Aalborg in the three inner circles of the city.

A test of duplicate sightings at addresses of hares in different areas of the city showed no difference between apartment blocks (5.4% duplicates) and residential areas (4.5% duplicates). However, there were significantly more duplicates in parks and cemeteries (14.5%) than in private gardens ($p < 0.001$) and between apartment blocks ($p < 0.01$) (Table A2).

3.1.3. Time of Day When Hares Were Seen by Citizens

There were 683 citizens who had reported the time when they had observed the hare. Most hares were seen in the morning hours between 6 am and 8 am, around two hours after sunrise, and later at night between 8 pm and 10 pm in the twilight hours around sunset (Figure 3).

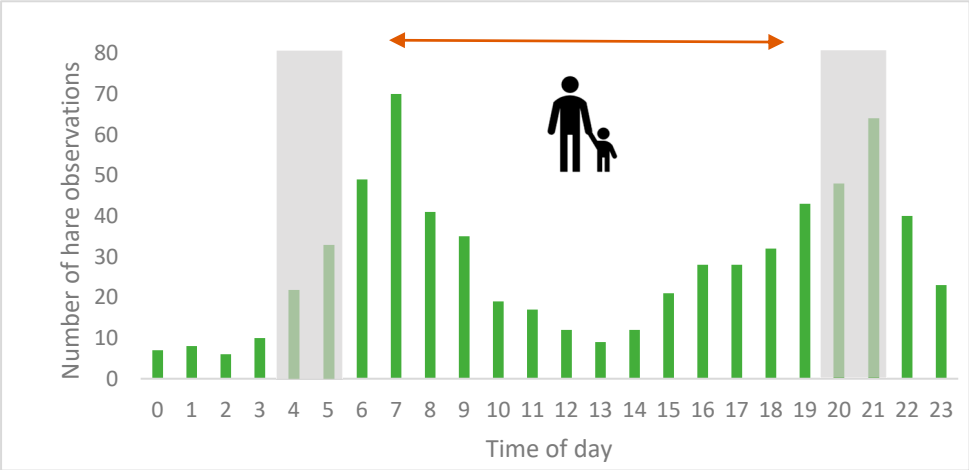

Figure 3. Time of day when hares were seen by citizens (n = 683). The horizontal arrow marks the time of day that humans are expected to be most active during the summer months. The vertical shadings represent twilight before and after sunrise and sunset from July to September.

The correlations between the cumulative percentile curves of the time at which the hares were observed in the different localities (apartment areas, private gardens, city centers, port areas, and commercial districts) were all highly correlated (range of r: 0.98–0.99; all: $p < 0.0001$) (Figure 4).

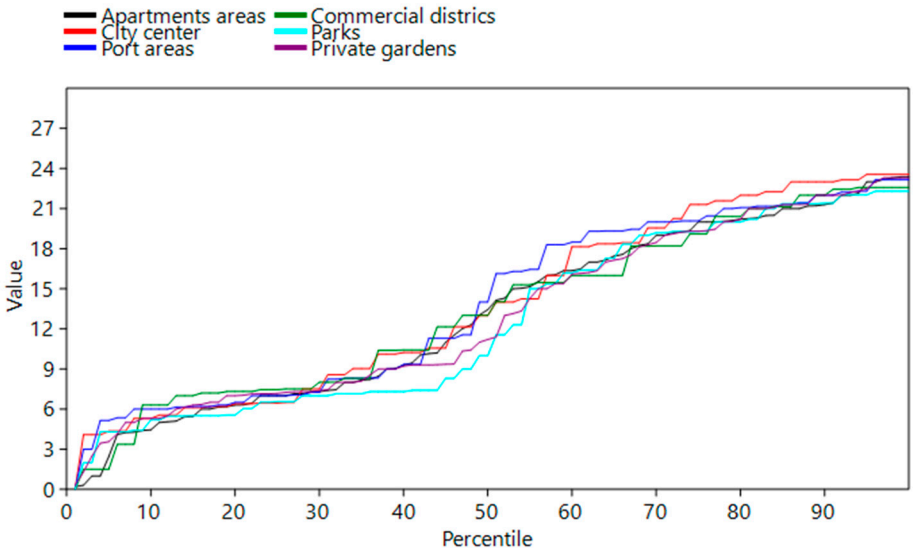

Figure 4. Correlations between the cumulative percentile curves of the time at which the hares were observed in the different localities (apartment areas, private gardens, city centers, port areas, and commercial districts) were all highly correlated (range of r; 0.98–0.99, all: $p < 0.0001$).

3.2. Monitoring Hares with a Thermal Spotter

Hares could easily be identified with the thermal spotter between the buildings at a distance of 50 m and due to the long ears of hares, they could be relatively easily separated from other mammals in the city (Figure 5). During the two nights at 12 locations, where citizens had reported hare sightings, the thermal spotter was used to scan the areas between 1800 and 2400 h (Table A3). No significant correlation was found between the number of hares reported at the locations by the citizens and the hares counted with the spotter. The thermal spotter revealed high densities of hares at the visited spots with an estimated mean

of 40.0 (±10.9 SE) hares per km^2. The number of hares seen by citizens at the 12 locations was 4–7 times higher than hares seen using the spotter (Table A3).

Figure 5. Photos of hares taken from video clips recorded using a thermal spotter. In the photo on the right-hand side, a hare can be seen in front of a parked vehicle (left in the photo).

4. Discussion

4.1. Are Urban Areas Better Habitats than Rural Habitats for Hares?

The decline in the hare population in agricultural areas, not only in Denmark but throughout Europe, gives reason to search for remaining quality habitats for hares. The increasing awareness of conserving biodiversity and not using pesticides in Danish cities and private gardens, allows wild weeds to grow in the green areas of urban areas. Greenspaces between apartment blocks in the city center of Danish cities may offer quality habitats for hares and may, therefore, have a conservation value for them. In areas where hares were spotted by the thermal spotter, the estimated mean number of hares (40 per km^2) was comparable with the highest densities of hares found in Europe in arable and mixed areas, where densities were on average 28 and 43 hares per km^2, respectively [7]. In contrast, in a recent Danish study in agricultural areas of Northern Jutland, the hare densities ranged from 1.5 to 10 hares per km^2 using spotlight counts and 4.8 to 14.1 hares per km^2 using a thermal drone [25].

If the habitats in urban areas are more densely populated with hares than in agricultural areas, a source–sink condition may occur where hares reproduce and disperse from urban areas to surrounding agricultural areas. The source–sink model implies that in a heterogeneous environment, some quality habitats may be important for the long-term survival of a population, and considering the presence of source–sink dynamics will help inform conservation decisions [28–30]. However, to act as a source habitat, urban areas need to have more advantages for hares, e.g., higher food availability and reproduction, than disadvantages caused by human interference (e.g., disturbance), leverets taken by dogs, cats, and foxes, and mortality due to other factors such as vehicles [30,31]. Population densities and breeding performance of some species are in fact higher, and home-range sizes are smaller in urban areas compared to surrounding agricultural areas [22,32–34]. As hunting is illegal in Danish cities, mortality due to hunting is eliminated, and predation risk may in some urban areas be reduced [24,35]; however, foxes are common in both Aarhus and Aalborg [36].

Some animals may display increased tolerance of humans, which agrees with reports from citizens of Aalborg and Aarhus, describing observations of hares not acting fearfully toward people passing by. In a study in urban and farmland areas in the Czech Republic and Austria, hares were found to adjust their escape behavior and escaped significantly earlier in farmland (rural) habitats than in urban habitats, indicating that the former populations were not conditioned to the presence of people [12].

4.2. Density of Hares in Different City Zones

Surprisingly, reports of hares were denser in the center of Aarhus and Aalborg, and the density of hares around apartment blocks was five times higher than reported from private gardens. As the comparison between apartment blocks and private gardens was based on sightings in the circular section between 1 km and 2 km from the city center, the preference is thought to reflect the density of hares and not the abundance of observers. We have no explanation for the preference for the lawns around apartment blocks rather than those of private gardens, other than it may be easier to spot predators from a longer distance. Another explanation may be that lawns around apartment blocks provide better feed throughout the year. Private gardens may also be more disturbed by peoples' dogs and cats. There are no stray dogs in Denmark, and predators in the city center are foxes, herring gulls (*Larus argentatus*), and corvids [36,37]. The significant declining trend in hare observation densities documented in this study shows a clear decline from the city center and outward for both cities. This declining trend may be due to the composition and amount of available acceptable habitats for the hares outside the city center.

4.3. Methods for Monitoring Hares in Urban Areas

Hares have not been studied in European cities to the same extent as foxes, badgers, and hedgehogs [16,17,38–40]. It is therefore not known whether hares have entered cities more recently than the other mammal species. Methods have been developed to estimate the population size of foxes using the density of scats or fox dens [41–45]. As hares do not den, only the densities of scats may be relevant to compare to citizen science methods or hares monitored by the thermal spotter. These methods will not always give the exact population size but a relative measure to compare fox densities between habitats.

Citizen reports can efficiently help to reveal hot spots for hares and other mammals within a city. However, citizen science data may be biased, because observers may not be evenly distributed in different parts of the city [21]. It is noteworthy that the very high correlations between the cumulative percentile curves confirm that there are very small biases in the times at which the hares are observed in the different localities. Also, there was no significant difference between the duplicate reports of hares that had been reported at the address between apartment blocks and private gardens, although the density of observers is expected to be higher around apartment blocks than in residential areas. There was, however, a significant difference between duplicate hare sightings in apartment areas, residential areas, and recreational areas such as parks and cemeteries. People may be more aware of their surroundings in their spare time.

In this study, a comparison between the density of hare reports by citizens compared to the counts by the thermal spotter revealed that reported densities by citizens most likely will overestimate the population size by four to seven times compared to the counts made by the thermal spotter. Hares move around, and the observations from citizens will be a concentration of observations over a longer period. Hares were seen at all times of the day, with a peak two hours before sunrise and just before sundown. The peaks around sunrise and sunset may not only reflect human activity but also hare activity. Also, hares in Southwest England during the summer period were found to be partly diurnal, with peaks in activity post-sunrise and pre-sunset, for a total of 6 h [46].

The estimated density of hares In areas pointed out as hare locations (mean 40 hares per km^2) was higher than the densities of hares found in the previous study in 2018 Aarhus (8 hares per km^2). However, this may be due to the different methods. In our study, we monitored hares by a thermal spotter at locations formally reported as hare locations, while in the study in Aarhus in 2018 the scientists walked in line transects during dusk. Also, most likely hares are more easily spotted with a thermal spotter than at dusk by the naked eye.

Citizen sightings were effective in identifying locations and habitats used by hares, but they were not an appropriate method to estimate population size. The thermal spotter with video function was shown to be valuable for detecting hares between buildings in highly populated areas. Hares could easily be spotted at a distance of up to 50 m, and the spotter did not cause unnecessary anxiety as the traditional spotlight counts of hares in cities. In future studies of hares in urban environments, we suggest a combination of citizen science and counts by the thermal spotter to reveal the actual population size. The thermal spotter could advantageously be used over a few nights during spring and autumn, to estimate the yearly population change in the city.

Cities with the proper management of green spaces may become important habitats for many different mammal species, including hares. There is a need for a better understanding of the urban habitat and population dynamics of mammalian species living in urban areas to improve cities for the benefit of and conservation of wildlife. Future monitoring studies using thermal spotters may point out urban habitats with the highest densities of hares. Such knowledge is of great importance for the future management of urban hares and other wildlife.

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Data Availability Statement: Data are unavailable due to privacy of citizens.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Figure A1. Examples of photos (13 pieces) of leverets send by citizens from Aalborg and Aarhus.

Table A1. The number of hares observed at different distances from the city center to outlying areas.

	Distance to Center	No. of Hare Locations Within Distance	No. of Hare Locations Inside Circle the Section	Area of Circle Section	Density of Hare Locations
Aarhus	1 km	77	77	2.95	26.12
It il	2 km	207	130	7.78	16.72
	3 km	307	100	11.10	9.04
	4 km	368	61	14.10	4.33
	5 km	444	76	17.04	4.46
	6 km	531	87	21.96	3.96
	7 km	560	29	26.57	1.09
Aalborg	1 km	103	103	3.14	32.79
	2 km	306	203	8.24	24.63
	3 km	451	145	14.88	10.02
	4 km	542	91	19.23	4.73
	5 km	595	53	24.98	2.12
	6 km	642	47	31.23	1.51
	7 km	648	6	36.08	0.17

Table A2. Chi^2 square test of double sightings of hares at the same address within 24 h in different parts of the city.

Location	Apartment Blocks	Private Gardens	Cemeteries/Parks	Industrial and Harbor Area
Apartment blocks	-	$\chi^2 = 0.19$, $p = 0.66$	$\chi^2 i^2 = 6.8$, $p < 0.01$	$\chi^2 = 3.8$, $p = 0.07$
Private gardens	$\chi^2 = 0.19$, $p = 0.66$	-	$\chi^2 = 11.1$, $p < 0.001$	$\chi^2 = 4.0$, $p < 0.05$
Cemeteries/Parks	$\chi^2 = 6.8$, $p < 0.01$	$\chi^2 = 11.1$, $p < 0.001$	-	$\chi^2 = 1.3$, $p = 0.26$
Industrial and harbor areas	$\chi^2 = 3.8$, $p = 0.07$	$\chi^2 = 4.0$, $p < 0.05$	$\chi^2 = 1.3$, $p = 0.26$	-

Table A3. Number of hares reported by citizens at various locations in Aalborg compared to hares spotted with thermal binoculars. Reported by citizens as incidences and (minimum number of hares).

Locality	Date	Time	Area Scanned	Reported by Citizens	Number Spotted	Hares per km^2/100 ha
Park and playground "Karolinelund"	30 May	18:08	3.84 ha	11 (16)	1	26
Cemetary Vesterbro	30 May	20:00	10.56 ha	11 (21)	3	27
Green site "Fjordmarken"	30 May	21:00	7.87 ha	3 (4)	4	51
Salt marsh Lindholm beach park	30 May	22:00	10. 20 ha	3 (7)	3	29
Area around apartment blocks "Carl Klitgårdsvej"	30 May	22:40	6.46 ha	9 (20)	0	0
Area around apartment blocks "Blegkilde"	18 September	20:40	9.65 ha	15 (24)	5	52
Area around apartment blocks "Borgmester Jørgensens Vej"	18 September	21:33	6.57 ha	4 (11)	4	61
Area around apartment blocks "Rughaven"	18 September	22:06	3.77 ha	6 (12)	3	25
Residential area "Øgadekvarteret"	18 September	22:31	10.43 ha	14 (18)	9	87
Green area at the harbor area	18 September	23:23	2.37 ha	26 (51)	3	125
Castle Park	18 September	23:38	1.48 ha	5 (6)	0	0
Park "Jomfru Ane"	18 September	23:54	1.09 ha	1 (1)	0	0
Mean number of hares per ha/km^2	-	-	-	168/297	-	40

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