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Urban populations of the red squirrel (*Sciurus vulgaris*) in Warsaw

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We conducted visual surveys of the red squirrel *Sciurus vulgaris* in 2005 in 11 parks and city forests of Warsaw with particular focus on the population in Łazienki Park in the city center. We found a significant association between the size of the park and the number of observed red squirrels, with the highest number occurring in Łazienki Park. In this park, the abundance index of the population in 2005 was 1.8 individuals per ha, which was three times higher than in 1956 and 1986, when similar surveys were carried out. The number of red squirrels observed in Łazienki Park was influenced by season, temperature, air humidity and tree species, the seeds of which are a potential food source for red squirrels.

Introduction

The red squirrel, *Sciurus vulgaris*, is one of the many animal species that have adapted to living in urban environments (termed synurbization by Andrzejewski *et al*. 1978). Towns and cities are mosaic habitats that have been created or transformed by humans, including city forests, parks, gardens and greenways (Chojnacki & Sudnik-Wójcikowska 1994). In Warsaw there are 82 parks ranging in size from 2 ha to 70 ha. The city's biodiversity is estimated at 4000 species of plants and animals (Luniak & Pisarski 1994). More mammal species tend to live in the suburbs than the city center although both the field mouse (*Apodemus agrarius*) and the red squirrel can be found in city centers (Andrzejewski *et al*. 1978, Luniak 2004). The aim of this study was to investigate the distribution and density of red squirrels in different types of forests and parks in Warsaw, with particular reference to the largest park, Łazienki. The relationship between park size and squirrel numbers, the annual cycle in numbers, and daily activity patterns were studied.

Study area

We conducted the study in 11 urban parks, cemeteries and city forests located in different parts of the center and the suburbs of Warsaw (Fig. 1). We conducted detailed analyses in Łazienki Park, the largest and oldest (established in the 18th century) park in Warsaw. Łazienki Park is located in the center of Warsaw, on the Vistula River escarpment, between busy streets. It covers an area of 76 ha, of which 68 ha is grass, trees, shrubs and paths. Ponds and buildings occupy the remaining area. Currently it is a landscape

park with preserved elements of a French garden. After meliorations, which were conducted in the 18th century, the landscape obtained a character of a dry-ground forest community with about 10 000 alien and native, trees and shrubs represented by 92 species. Tree stands cover 70% of the Park's area and 27% of the trees have reached an age of more than 130 years.

Materials and methods

Red squirrels were surveyed visually according to the method suggested by Andrzejewski (1956). This method is similar to the visual count methodology used by others (e.g. Gurnell *et al*. 2001). At 10 study sites we directly observed red squirrels on visual transects 600-m to 2500-m long, depending on the size of the area. The lines had a fixed width of 20 m on either side of the central line and were divided into 40-m-long segments. The area of the transect lines varied from 2.4 to 10 ha. We observed red squirrels on both sides of the line, both on the ground and in trees. The study was conducted in January, April, July and October of 2005. Each line was sampled three times per month. Altogether we carried out 120 observations, during which we saw red squirrels 2314 times (M. Żak unpubl. data).

In Łazienki Park we conducted more detailed observations of the red squirrel population. Andrzejewski (1956) and Dmytruk (1986) carried out similar studies in the same area using similar methods. Andrzejewski (1956) observed red squirrels in 25 of the above-described segments (1000 m), while Dmytruk (1986) studied 63 segments (2520 m) including the 25 segments proposed by Andrzejewski (1956). The research that we present in this work involved an even larger area. We carried out direct observations on a transect 4.4-km long, divided into 111 segments. Because we conducted the observations on both sides of the transect, at a distance of 20 meters, the whole assessment strip covered an area of 18 ha, which relates to 26% of the Park's area. Assuming that red squirrels occur in the same proportion in the entire park as on the assessment strip, we estimated an abundance index, i.e. the number of red squirrels per ha. Squirrels were easiest to see in the autumn and winter when foliage did not make observations difficult. The abundance index was estimated for each period.

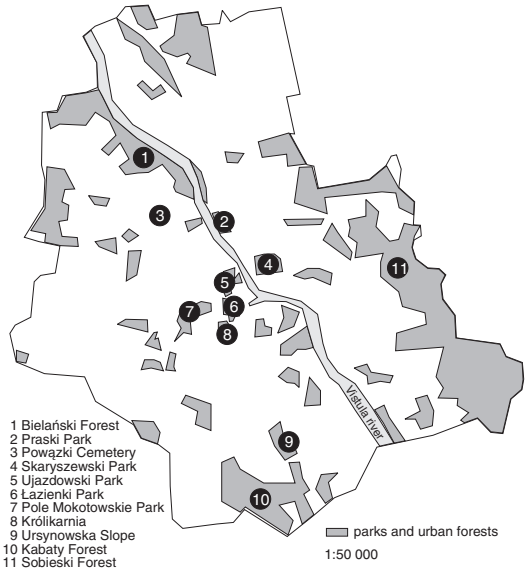

Fig. 1. Location of study areas in Warsaw.

We carried out observations in the morning, between 8 and 10 a.m., twice a week (on one working day and during the weekend), throughout 2005. The year was divided into 4 seasons: winter (January–March), spring (April–June), summer (July–September), autumn (October–December). Altogether we carried out 85 patrols of the park, during which we encountered red squirrels 2946 times.

Additionally, during each visual survey we counted walkers and noted weather conditions. Data regarding temperature (°C), air humidity (%) and barometric pressure (hPa) were obtained from the meteorological station of the Warsaw Technical University. We did the inventory of trees and shrubs on the basis of maps and catalogs received from the Łazienki Park Directory, which we later verified in the field. On the basis of literature concerning the food preferences of the researched rodents (Moller 1983, Wauters *et al*. 1992, Margis & Gurnell 2002), among all tree and shrub species growing in the park we chose a few which seemed significant for red squirrels. They were classified into six groups: 1 = coniferous trees, 2 = deciduous trees (walnut, hazel), 3 = deciduous trees (beech, hornbeam, oak), 4 =

coniferous and deciduous trees (walnut, hazel), 5 = coniferous and deciduous trees (beech, hornbeam, oak), 6 = deciduous trees (walnut, hazel, beech, hornbeam, oak).

In order to determine the daytime activity of red squirrels we carried out visual surveys on assessment strips from 8 a.m. until dusk, in two-hour-long blocks. We performed 6 visual surveys in the spring (April) and the summer (July) and four visual surveys in the autumn (October) and the winter (January). We based the daytime activity on 754 red squirrel observations.

We characterized the assessment trail in the park on the basis of the number of red squirrels observed on each of the segments. We used a six-level scale. We recognized as 'most attractive' the segments with 81–85 red squirrel observations, as 'attractive' those on which 60–80 observations took place, as 'medium attractive' those with 40–60 observations, 'less attractive' 20–40 observations, 'little attractive' < 20 observations, and 'unattractive' those segments on which we observed no red squirrels.

Results

We ascertained the presence of red squirrels in all the researched areas of urban green in Warsaw. In the researched parks, the average number of observed red squirrels per 1 km of the assessment trail differed from 0.22 to 7.88 individuals (Table 1). We observed the highest number of red squirrels in the parks located in the city center as compared with that in suburban forests (Fig. 1).

We converted the number of red squirrels observed on the assessment strips to the number seen in the park area. We ascertained the highest abundance index of red squirrels in Łazienki Park (1.8 individuals per ha) and the lowest in the forests situated in the suburbs: Kabaty Forest (0.004 individuals per ha), Bielany Forest (0.023 individuals per ha) and Sobieski Forest (0.033 individuals per ha). We found a significant dependence between the size of the urban green area and the number of observed red squirrels (Fig. 2). This means that in larger city parks we found higher numbers of red squirrels.

In order to determine any changes in the abundance index in Łazienki Park during the last 50 years we selected data from the same 25 segments (4 ha) on which in 1956, 1986 and 2005 visual surveys were conducted. We estimated the number of seen red squirrels in the area of 4 ha and the abundance index. In this park in 2005 the abundance index of the red squirrel population was three times higher as compared with that in previous years (Table 2).

Season had a strong effect on the number of observed squirrels in Łazienki Park (ANOVA: $F_{3,43} = 6.87$, $p < 0.0008$). In late autumn and winter, when there was no foliage on the trees, we observed much higher numbers of red squir-

Table 1. Visual count of red squirrels in different types of parks in Warsaw.

Park	Surveys (*n*)	Total number of red squirrels seen	Average number of red squirrels seen per survey	SD	Average number of red squirrels seen per kilometer	SD
Łazienki Park	85	2946	34.65	16.89	7.88	3.86
Praski Park	12	137	11.42	6.07	3.44	1.93
Skaryszewski Park	12	146	12.17	7.25	2.35	1.43
Królikarnia	12	63	5.25	2.90	2.20	1.27
Pole Mokotowskie Park	12	108	16.62	5.75	1.80	1.23
Powązki Cemetery	12	110	9.17	5.54	1.74	1.05
Ujazdowski Park	12	45	3.75	2.18	1.52	0.94
Ursynowska Slope	12	51	4.25	2.49	0.41	0.25
Bielański Forest	12	27	2.25	1.54	0.26	0.19
Kabaty Forest	12	32	2.67	2.06	0.25	0.20
Sobieski Forest	12	27	2.25	1.66	0.22	0.17

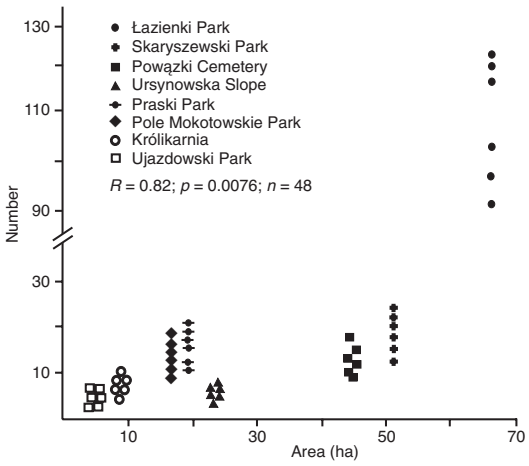

Fig. 2. Correlation between the number of red squirrels seen and the area of researched urban green.

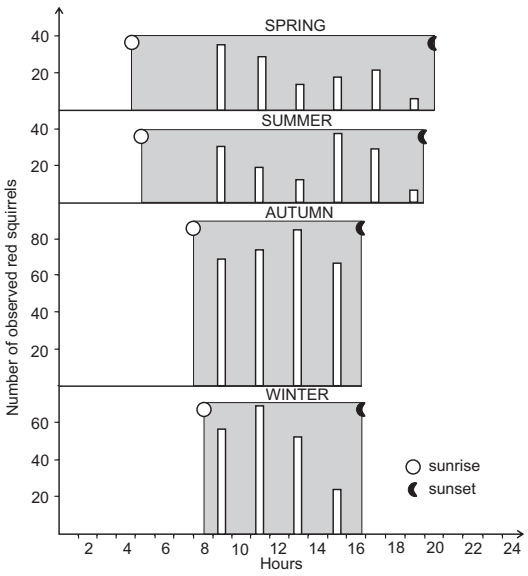

Fig. 3. Daily activity patterns of the red squirrel during different seasons in Łazienki Park.

rels (respectively 48 and 42 individuals/survey of the trail) than in spring and summer (31 and 20 individuals/survey of the trail). At higher temperatures (spring and summer), we observed a significantly lower number of red squirrels ($y = 42.64 - 0.996x$, $p < 0.001$, $r = -0.55$, $n = 85$) as compared with that at lower temperatures (autumn and winter). Also air humidity significantly affected the number of observed red squirrels ($y = 11.96 + 0.350x$, $p < 0.02$, $n = 85$, $r = 0.25$, $n = 85$).

We also investigated whether the presence of walkers influences the number of observed squirrels. As compared with other seasons, we observed the highest number of visitors (47%) in the spring, and significantly more on weekends than on working days (Student's *t*-test: $p < 0.04$, $n = 85$). For the whole year we found no significant correlation between the number of observed red squirrels and the number of walkers.

In Łazienki Park, red squirrels were active during the entire day. Because the lengths of days differ throughout the year we determined when after sunrise activity of red squirrels was at its highest. We found that in spring and summer, as the days got longer, red squirrels had two activity peaks, the first one in the morning hours and the second one in the afternoon. During the autumn and winter, the days being very short, we found only one activity peak in the morning hours. As the days became shorter the red squirrels' activity peak moved towards earlier hours. In the spring we observed the second peak at 5 p.m. (13–15 hours after sunrise), and in the summer at 3 p.m. (between the 9th and 11th hour after sunrise). During the autumn and winter, there was only one activity peak (at 1 p.m. during autumn, between the 5th and 7th hour after sunrise, and at 11 a.m. in winter, between the 3rd and 5th hour after sunrise) (Fig. 3).

We also investigated whether particular parts of the park were used more frequently than others by red squirrels. We never observed red

Table 2. Number and abundance index of red squirrels in Łazienki Park (*Andrzejewski 1956, **Dmytruk 1986).

Year	Average number of red squirrels seen per 4 ha	Estimated number of red squirrels in Łazienki Park (68 ha)	Red squirrels' abundance index per 1 ha
1956*	2.6	44	0.6
1986**	2.1	36	0.5
2005	7.0	119	1.8

squirrels in only 4 of the 111 segments. Concurrently only 5% of the assessment trail was attractive for red squirrels (we saw the animals every second survey). In the remaining 95% of the segments we rarely saw red squirrels (every fourth survey or less frequently).

We characterized the assessment strip in Łazienki Park on the basis of the number of red squirrel encounters in individual segments. The applied six-level scale showed that the most attractive segments made up only 9% of the whole survey trail. The attractiveness of the segments changed with seasons, which was especially visible during winter. In winter those segments which were near the Park entrance gained attractiveness.

Next we verified, whether the seasonal occurrence of red squirrels in particular segments of the assessment trail in Łazienki Park was connected to the presence of trees and shrubs. The highest number of red squirrels was seen in trees from group 5 (coniferous and deciduous trees such as beech, hornbeam and oak). The number of red squirrels depended on season: it was higher during the autumn and winter in comparison with that in the spring and summer. When we analysed group 3, deciduous trees (beech, hornbeam, oak), and group 6, deciduous trees (walnut, hazel, beech, hornbeam, oak), we found a much lower number of red squirrels in comparison with that in the previously analysed tree group but still observed a similar seasonal dependence. When we separately analysed the following tree groups: 2 = deciduous trees (walnut, hazel), 1 = coniferous trees, and 4 = coniferous and deciduous trees (walnut, hazel) red squirrels were scarce or were not seen at all (Table 3). This was confirmed by results of a two-way ANOVA in which tree groups and season, and their interaction, were highly significant (Table 3).

Discussion

In Europe the red squirrel occurs in coniferous and deciduous forests as well as in parks and gardens. These are the places where research concerning this species is most frequently conducted. The result of these studies is a large amount of information concerning the biology and ecology of the red squirrel (e.g., Gurnell *et al*. 2001, 2004, Wauters & Dhondt 1990, Wauters *et al*. 2000). The red squirrel can be seen not only in natural conditions but also in different types of urban green space. However, there are not much data about red squirrels living in these specific conditions (Lee & Fukuda 1999, Luniak 2004). This is surely due to methodological difficulties and the use of only a few possible research methods. Most often five direct methods of red squirrel monitoring are used (Gurnell *et al*. 2001). They are: visual surveys, hair tube surveys, drey counts, feeding transects and whole maize baits. All these methods can successfully be used in natural conditions. In cities, except for visual surveys and drey counts, the applicability of the other methods is limited mostly

Table 3. Average numbers of red squirrels seen in Łazienki Park by chosen groups of trees in the seasons.

Group of trees	Spring	Summer	Autumn	Winter
1. Coniferous trees	0.048	0.095	0.476	0.238
2. Deciduous trees (walnut, hazel)	0	0	0	0
3. Deciduous trees (beech, hornbeam, oak)	3.905	2.190	6.381	4.762
4. Coniferous and deciduous trees (walnut, hazel)	0.238	0.143	0.333	0.667
5. Coniferous and deciduous trees (beech, hornbeam, oak)	8.619	6.714	16.143	14.286
6. Deciduous trees (walnut, hazel, beech, hornbeam, oak)	4.143	3.190	6.571	6.522
Source of variation	df	*F*		
Group of trees (A)	5,120	202.11***		
Seasons (B)	3,360	23.38***		
Interaction (AB)	15,360	6.36***		

***$p < 0.0001$.

due to human presence. Parks and city gardens are regularly cleaned making feeding transects impossible. The whole-maize bait method does not work either because the feeding traces of red squirrels, which must be analyzed, are cleaned by park management. Hair-tube surveys are used to distinguish between the red and the grey squirrel (*Sciurus carolinensis*), which does not occur in Poland.

In this study we used visual surveys of red squirrels, a method which according to Gurnell *et al*. (2001) is the standard method of research of this species. This choice was made because in Poland the red squirrel is a protected species. It was essential to use a non-invasive method, which would not cause interest and protests from visitors of the researched parks. This method, like all others, is certainly imperfect (Gurnell *et al*. 2001). The largest error caused by this method in areas of urban green space is the possibility of counting one individual several times or not noticing individuals among tree branches. We tried to limit this error in the following ways. Firstly, the assessment strips ran through the Park in different directions and did not overlap. Secondly, the survey was done relatively quickly.

In the autumn and winter we observed significantly more red squirrels than in other seasons. This was caused by the fact that in parks and city forests there are highly diverse tree and bush communities with large numbers of deciduous species causing difficulties in direct surveys of red squirrels. It seems that the surveys should be conducted in the autumn and winter when foliage does not hamper observations.

During this study we observed numerous red squirrels. Numbers varied from 0.22 in the suburbs to 7.88 per km in the city center. This was higher as compared with the abundances in natural conditions (0.22–1.36) (Gurnell *et a*l. 2004). A high abundance index of red squirrels in the city was also found. It differed from 0.004 individuals per ha in the suburb forests to 1.8 individuals per ha in the city center parks. In natural forests the abundance index varies from > 0.1 to 1.4 individuals per ha (Wauters *et. al*. 1994, Lurz *et al*. 1995, Wauters *et al*. 2004).

In this study we did not investigate red squirrel home range sizes. Dmytruk (1986) estimated that in Łazienki Park, red squirrels have home range sizes of about 1.1 ha, but Verboom and Van Apeldoorn (1990) stated that in different habitats home range sizes vary from 1.5 to 13.4 ha. In Łazienki Park in 2005, we estimated the number of red squirrels at 119 individuals, which means that in an area of 1 ha there were on average two red squirrels. It can be assumed that their home ranges overlap or are smaller than those known from the literature.

It appears that a rich food source may be the cause of high numbers of red squirrels in urban green space. City parks are most often areas with old tree stands of both native and alien origin and high species diversity. Łazienki Park is an example of such an urban green area. The high numbers of red squirrels in this park result from the fact that this park is an ideal habitat for squirrels. Here the presence of old coniferous and deciduous trees and high species diversity, which according to Magris and Gurnell (2002) provide a year-round food source for red squirrels, are important. In this study we showed that red squirrels were most frequently seen in places with coniferous and deciduous trees such as beech, hornbeam and oak. In city parks, red squirrels reach much higher densities because they not only use natural food sources but are also fed by humans. Red squirrels use food provided by visitors, usually different kinds of nuts. We noticed this frequently during our investigations. Besides this, animals inhabiting city parks feed on the contents of waste bins. Analyses of the stomach contents of striped field mice (*Apodemus agrarius*) living in Warsaw's parks showed the presence of antropogenic food (Babińska-Werka 1981). The red squirrel may also use this food source.

The second reason for the high number of red squirrels in city parks may be the fact that there are only a few predators in these parks — goshawks (*Accipiter gentiles*) and martens (*Martes martes*) (Luniak 1996, Luniak *et al*. 2001). However, recently in Poland, a growth in the number of several predatory mammal species, which enter urban green space, has been noted. These predators may have an effect on the red squirrel population inhabiting city parks and forests.

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