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Density of red squirrels and their use of non-native tree species in the Rogów Arboretum

Dagny Krauze-Gryz[1*], Kinga Mazur[1], Jakub Gryz[2]

[1]Warsaw University of Life Sciences – SGGW, Faculty of Forestry, ul. Nowoursynowska 159, 02–776 Warszawa, Poland; [2]Forest Research Institute, Department of Forest Ecology, Sękocin Stary, ul. Braci Leśnej 3, 05–090 Raszyn, Poland

*Tel. +48 22 5938145, e-mail: dagny.krauze@wl.sggw.pl

Abstract. The aim of the study was to compare the densities of red squirrel (*Sciurus vulgaris*) in the arboretum and a neighbouring forest and to investigate which tree species the squirrels used. The study was conducted in the area of the Rogów Arboretum (53.76 ha) and the so-called Zimna Woda and Wilczy Dół forest complexes (altogether 536 ha), all being part of an Experimental Forest Station in Rogów. The density of squirrels in the arboretum and the neighbouring forest was estimated and compared by means of snow tracks on transect routes. Changes in the abundance of squirrels throughout one year as well as their behaviour were determined on the basis of direct observations along transects running through the arboretum. More than half of the area of the arboretum was searched in order to record feeding signs of squirrels. Additionally, trees with bark stripping were recorded.

The density of snow tracks was higher in the arboretum (0.19 tracks/100 m/24 h) than in the neighbouring forest (0.09 tracks/100 m/24 h). The largest number of observations of red squirrels along transects was made between February and April, in July and August and in October and November. In about half of the cases, squirrels were feeding on one of six non-native tree species (most often on cones of Macedonian pine, *Pinus peuce*). Feeding signs were found on 39 plots (17%) and 16 different tree species. The most numerous feeding signs were found on plots with Douglas fir (*Pseudotsuga menziesii*) and also on plots with the western hemlock (*Tsuga heterophylla*), Swiss pine (*Pinus cembra*), mountain silverbell (*Halesia monticola*) as well as shagbark (*Carya ovata*) and shellbark hickories (*C. laciniosa*). On eight plots, trees with signs of bark stripping were found, most commonly on Sawara cypress (*Chamaecyparis pisifera*). Its soft bark was probably used to build dreys. In the area of the arboretum, the natural food sources (seeds of native trees) are supplemented with numerous non-native tree species, which seeds are also consumed by squirrels. The highly abundant and diverse food sources promote a higher density of the red squirrel in the area of the arboretum. Additionally, when tree seeds are scarce in the neighbouring forest, squirrels migrate into the arboretum.

Keywords: *Sciurus vulgaris,* live traps, snow tracking, visual counts, feeding signs, bark stripping

1. Introduction

Red squirrel could primarily be found in forests of northern Eurasia (Shar et al. 2008). It is a very flexible species, which can easily adapt to mild environmental changes. That is why red squirrel could be found in natural forests (Stachura et al. 2004) and also in small wooden areas on agricultural lands (Wauters 1997) as well as city parks (Babińska-Werka, Żółw 2008; Krauze-Gryz et al., unpublished.), where squirrels feed on various types of food offered by people (Krauze-Gryz, Gryz 2015). Red squirrel consumes variety of foods. Its diet depends on the environment where squirrel is found and also changes throughout the year depending on food availability (Krauze-Gryz, Gryz 2015). However, red squirrel more highly prefers seeds of coniferous and broadleaved trees, whilst squirrel population density fluctuates depending on the seed availability (Lurz et al. 1995;Wauters et al. 2008). Red squirrel population densities are higher in places where food availability is steady throughout the year (Wauters et al. 2008). During the periods when main food supply of tree seeds is low, red squirrels try to locate the more productive tree groups within their forest, increase their home ranges or migrate (Lurz et al. 2000;Wauters et al. 2005).

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The Rogów Arboretum is a vast area presenting a rich food base, which includes tree seeds from native and introduced species. High species diversity of trees producing seeds in different terms results in a more stable supply of food within the arboretum area compared to the surrounding forests. It could be predicted that during the years with low yields of seeds produced by the main forest species making up the surrounding to arboretum forests, squirrels from those areas would shift to the arboretum area in search of food supply. It could also be assumed that because of the rich food supply, red squirrel densities within the arboretum could be higher than those in surrounding forests.

The goal of the current study was to compare densities of red squirrels within the arboretum with squirrel densities in nearby forests, as well as identifying which non-native tree species are used by squirrels and in which way (feeding on seeds, bark stripping).

2. Study area

The research was conducted within the area of the arboretum (53.76 ha) and also in the neighbouring Zimna Woda and Wilczy Dół forest complexes (altogether 536 ha) which are part of the Experimental Forest Station in Rogów. The arboretum was founded in 1925. Fragments of the forest that existed before the arboretum was organised include 150-year old pines (*Pinus sylvestris*) and also spruces (*Picea abies*), oaks (*Quercus* spp.) and European hornbeam (*Carpinus betulus*). The arboretum has the collection of tree species (from 2,837 taxa), tropical plants (growing in the greenhouse), herbaceous and alpine species. Forest experimental areas cover the significant part of the arboretum (in total 18 ha), where 75 non-native tree species are growing (including 50 coniferous species). Undeveloped part of the arboretum is covered by the 80-year old forest with pine being the dominant tree species (Tumiłowicz 1993; http://arboretum.sggw.pl).

Pine is also a dominant tree species of the commercial forest that stands neighbouring the arboretum with oak and larch (*Larix* spp.) which have significant shares in those forests. Stands with multiple tree species are more common. Both in the arboretum and in nearby forest complexes, fresh broadleaved and fresh mixed broadleaved site types prevail (Zielony 1993).

3. Methods

3.1. Comparison of red squirrel densities in the arboretum and nearby forest complexes

In December 2014 and January 2015 (during five days altogether), observations were conducted on transects with the length from 200 to 1,000 m located evenly in the area of the arboretum (11 transects with the combined length of 6,850 m) and in nearby commercial forests (19 transects with the combined length of 13,000 m). Total length of the observation trails amounts to 8,600 m in the arboretum and 19,100 m in the commercial forests. The number of snow tracks left by red squirrels was registered on 100-m trail sections. Based on those observations, snow track density was calculated (N/100 m/day) for the arboretum and also for the commercial forests. The observations in arboretum and the commercial forests were conducted on the same day in order to minimise the influence of factors such as snow depth and surrounding temperature on red squirrel activity as well as study results.

3.2. The use of non-native tree species by red squirrel

Direct squirrel observations

Five evenly located transects with the width of 40 m (Babińska-Werka, Żółw 2008) and the length of 500–900 m (3600 m in total) were laid down in the arboretum (Fig. 1). Observations covered the area of about 14.4 ha, which is about 27% of the total arboretum area. Control observations were conducted from April 2014 to March 2015, averaging two times per month (29 control observations in total). Observations were done in the morning (from 7:30 to 11:30) under favourable weather conditions, which represents the time of peak squirrel activity (Wauters, Dhondt 1987; Bosch, Lurz 2012). The number of squirrels, their behaviour and also a tree species where squirrel was located were noted.

Registering feeding signs

The developed part of the arboretum is divided into sectors with different areas (Fig. 1). The search for feeding signs of red squirrels was conducted during seven control observations (in April, May, September and November of 2014) within the arboretum sectors. Study plots were set along the transect routes about 20 m apart from each other. Conifer cones or shells of broadleaved tree seeds with signs of red squirrel feeding were registered. The areas with mature trees producing seeds were selected.

The areas with very young trees not producing seeds, areas covered with dense shrub vegetation hindering observations, as well as areas with herbaceous and ornamental vegetation not used by red squirrels were avoided. In total, 228 plots were controlled, which amounts to 63% of all plots within the arboretum area (Fig. 1).

Bark stripping

Control observations intended for study of the use of bark by red squirrels were conducted in May 2015. Moving along the five transect routes (Fig. 1), observers noted trees with bark damaged by red squirrels. Furthermore, the number of all trees of a given species was counted as well as those trees damaged by squirrels.

Figure 1. Studied plots in the area of Rogów Arboretum and transect routes for direct observations of red squirrels

Data analysis

The difference between snow track densities in the arboretum and commercial forests was assessed by Student's t-test. Normal distribution was tested by the Shapiro–Wilk test. Statistical analysis was implemented by using the Past3 programme.

4. Results

4.1. Red squirrel densities in the arboretum and the commercial forests

The average snow track density in the arboretum was higher and equal to 0.19 tracks/100 m/day, whilst in neighbouring forest, it was equal to 0.09/100 m/day ($t = 2.4$; $p < 0.05$).

4.2. The use of non-native tree species by red squirrels

Direct observations

Red squirrels were observed in total 59 times on transect routes. Observations were not distributed evenly (Fig. 1). Most of the observations (30 cases) were done on the first transect, whilst there were no red squirrel observation on the fifth transect. About half of the observed squirrels were foraging (29 cases), including 5 cases of foraging on the ground. In the remaining cases, the animals were showing breeding behaviour, moving in tree crowns or on the ground, resting, or water from tree stump. Red squirrels feeding on tree seeds were observed on Macedonian pine (*Pinus peuce*) (eight observations), Scots pine (*Pinus sylvestris* L.) (four observations), eastern black walnut (*Juglans nigra*) (four observations), mountain silverbell (*Halesia monticola*) (three observations), white walnut (*Juglans cinerea*) (two observations), shellbark hickory (*Carya laciniosa*) (two observations), common hazel (*Corylus avellana*) (one observation). On the ground, red squirrels were foraging under lime trees (*Tilia* spp.) (three observations) and dawn redwood (*Metasequoia glyptostroboides*) (two observations.). One-fifth (12 squirrels) was observed on fir trees: Caucasian (*Abies nordmanniana*), noble (*Abies procera*), Greek (*Abies cephalonica*) and Nikko (*Abies homolepis*); however, in none of those cases, squirrels were foraging.

The number of red squirrels observed on transect trails has been changing throughout the year (Table 1). On an average during one daily control, two squirrels were seen, with the maximum seen in February (4.3 observations/control) and minimum in January and May (0.5 observations/control). More often red squirrels were seen in the arboretum from February to April (3.0–4.3 observations/control), followed by the period of July–August (1.8–2.5 observations/control) and then by October-November (2.3–3.0 observations/control). The share of foraging squirrels was different (Table 1). In January and February, there were no foraging individuals, in March only one out of six observed animals was foraging. In June, October and December, half of the observed squirrels were foraging, and during the remaining months (April, July, September and November), the majority of the observed squirrels were foraging. In August, red squirrels were seen five times and all those times squirrels were foraging.

Table 1. Number of observations of red squirrels and their behaviour as based on direct observations along transects in the area of Rogów Arboretum

Month	Behaviour		*n* controls	*n* observations/ control
	Feeding	Others		
01		1	2	0.5
02		13	3	4.3
03	1	6	2	3.5
04	2	1	1	3.0
05		1	2	0.5
06	1	1	2	1.0
07	4	3	4	1.8
08	5		2	2.5
09	2	1	2	1.5
10	2	4	2	3.0
11	5	2	3	2.3
12	2	2	4	1.0
Total	24	35	29	2.0

Feeding signs

Feeding signs were found on 39 study plots (17% plots studied), where red squirrels used 16 non-native tree species (Fig. 1, Table 2). Besides that, there were multiple signs of squirrel feeding on cones of Scots pine and Norway spruce (*P. abies*). Most of the studied plots had Douglas fir (*Pseudotsuga menziesii*) on them, whilst on most of those plots (10 out of 11), there were feeding signs on Douglas fir cones. Red squirrel feeding signs were often found on cones of Macedonian pine (on four plots), western hemlock (*Tsuga heterophylla*) and Swiss pine (*Pinus cembra*) (on three plots), and amongst broadleaved species on mountain silverbell (on five plots) and seeds of shagbark hickory (*Carya ovata*) and shellbark hickory (*C. laciniosa*) (on three plots). There were no red squirrel feeding signs on 198 study plots. Sixty seven of those plots had a non-native tree species as a dominant (Table 3). Remaining 13 plots had native tree species being dominant (Scots pine in 10 plots, Norway spruce in 1 plot, Scots elm (*Ulmus glabra*) in 1 plot and European white elm (*Ulmus laevis*) in 1 plot). On 109 study plots with no feeding signs of red squirrels, it was not possible to determine a dominant tree species.

Table 2. Alien tree species with feeding signs of red squirrels on their seeds, recorded during controls of the plots in the arboretum

No.	Species	Number of plots	
		checked	with feeding signs
1	*Pseudotsuga menziesii*	11	10
2	*Tsuga heterophylla*	4	3
3	*Picea omorica*	2	2
4	*Picea asperata*	1	1
5	*Picea schrenkiana*	1	1
6	*Larix gmelini*	3	1
7	*Pinus peuce*	5	4
8	*Pinus cembra*	4	3
9	*Pinus strobus*	3	2
10	*Pinus armandii*	1	1
11	*Pinus nigra*	1	1
12	*Juglans nigra*	3	2
13	*Juglans cinerea*	2	2
14	*Carya ovata*	3	3
15	*Carya laciniosa*	3	3
16	*Halesia monticola*	5	5

*native species outside its natural range

Bark stripping

Eight study plots had trees with bark stripped by red squirrels. Six of them had western red cedar (*Thuja plicata*) as a dominant species. The damages were noted on 19.4% of trees (n = 418). The bark damage often occurred on sawara cypress (*Chamaecyparis pisifera*), which is present in two study plots (36%, n = 125). Bark stripping was also observed on Japanese red cedar (*Cryptomeria japonica*) (on four out of four trees) and dawn redwood (*M. glyptostroboides*) (on one out of four trees). There was also one case of bark stripping on Père David's maple (*Acer davidii subsp. grosser*).

5. Discussion

With the use of the relative quantification method, snow tracking on transects, it was possible to conclude that red squirrel density in the arboretum was higher than that in the forests adjacent to it. It could result from influx of individuals from the surrounding areas during the time of food scarcity (Wauters et al. 2005). Besides, it could be assumed that rich food base from numerous coniferous and broadleaved tree species (such as walnuts and hickories) allows for higher squirrel densities.

The number of observed red squirrels in the arboretum was variable. Three culminations in squirrel quantities were observed in winter and early spring (February–April), summer (July–August) and autumn (October–November). Although the width of observation pass was chosen in a way limiting the error related to changing possibilities of squirrel observations linked to vegetation density, the probability of squirrel spotting in tree crowns is higher during bare tree season (Babińska-Werka, Żółw 2008). The number of red squirrels observed on transects could also depend on seasonal variations in their abundance, which peaks in autumn after the end of reproductive season. Squirrel numbers could also be affected by seasonal changes in activities of animals, which is lower during winter when temperatures are low (Wauters, Dhondt 1987; Bosch, Lurz 2012). In the Łazienki Park in Warsaw, significantly higher numbers of red squirrels were observed on transects in autumn and winter (Babińska-Werka, Żółw 2008), whilst in the Skaryszewski Park in Warsaw, it was higher in spring (from March to April) and later in summer and autumn (from August to November) (Prus 2014). The pattern observed by the discussed study partially agree with the data from the Skaryszewski Park (the average number of animals observed during a single control observation was higher in spring and autumn). The additional peak in number of red squirrels during summer could be explained by the influx of individuals from surrounding forest areas at the time of seed ripening on walnuts or hickories.

Table 3. Tree species dominating on plots where no feeding signs of red squirrels were found

No.	Species	Number of plots
1	*Abies lasiocarpa*	1
2	*Abies cephalonica*	3
3	*Abies concolor*	3
4	*Abies holophylla*	1
5	*Abies homolepis*	2
6	*Abies grandis*	7
7	*Abies sachalinensis*	1
8	*Abies sibirica*	1
9	*Abies procera*	3
10	*Abies veitchii*	1
11	*Abies naphrolepis*	1
12	*Picea mariana*	1
13	*Picea rubens*	1
14	*Picea sitchensis*	1
15	*Larix decidua*	2
16	*Larix kaempferi*	2
17	*Larix polonica*	1
18	*Larix eurolepis*	1
19	*Calocedrus deccurens*	1
20	*Pinus koraiensis*	2
21	*Pinus contorta*	1
22	*Pinus ponderosa*	1
23	*Metasequoia glyptostroboides*	1
24	*Thuja plicata*	6
25	*Chamaecyparis pisifera*	2
26	*Chamaecyparis obtusa*	1
27	*Fagus orientalis*	1
28	*Quercus palustris*	2
29	*Quercus rubra*	5
30	*Quercus pubescens*	1
31	*Quercus montana*	1
32	*Cercidiphillum japonicum*	1
33	*Magnolia acuminata*	1
34	*Acer saccharum*	1
35	*Acer rubrum*	1
36	*Fraxinus americana*	1
37	*Fraxinus chinensis*	1

The majority of 16 tree species on which red squirrel feeding signs were observed in the Rogów arboretum do not grow naturally within red squirrel distribution area. They include Douglas fir and western hemlock, species originating from North America, on which most of the feeding signs were found, and also dragon spruce (*Picea asperata*), eastern white pine (*Pinus strobus*) as well as Armand pine (*Pinus armandii*). It is known that seeds of coniferous trees constitute a basic diet of red squirrels living in boreal forests (Krauze-Gryz, Gryz 2015). Numerous feeding signs were also found on eastern black walnut (*Juglans nigra*) and white walnut (*Juglans cinerea*) as well as on shellbark and shagbark hickories originating from the United States. Indeed, red squirrels readily select nuts (walnuts and hazelnuts) as their source of food in both broadleaved and mixed forests, likewise as food presented to them by people in city parks (Moller 1983; Krauze-Gryz, Gryz 2015). Black pine (*Pinus nigra*) deserves a special attention amongst species used by red squirrels as their food source. Its seeds (besides Scots pine) constituted a basic diet of squirrels in Belgium (Wauters, Dhondt 1987; Wauters et al. 1992), the Formby Nature Reserve in England (Shuttleworth 1997), and also in Japan (Lee 2002). Also the seeds of Swiss pine (*P. cembra*) were listed as a key food source of squirrels in Russia (Moller 1983).

Red squirrel foraging was not confirmed on 39 species. Some of them, such as lodgepole pine (*Pinus contorta*) constitute food basis of squirrels in some areas (Bosch, Lurz 2012). It is also known that squirrels readily eat seeds of Korean pine (*Pinus koraiensis*) (Lee 2002) and also spruces (Moller 1983). No feeding signs of squirrels were found on acorns or larch cones, although they could be eaten by squirrels (Bosch, Lurz 2012; Krauze-Gryz, Gryz 2015). Similarly, squirrels did not consume maple seeds (two species) or ash (*Fraxinus* spp.) seeds (two species), even though they could be used by squirrels. For example, squirrels in Japan ate seeds of mono maple (*Acer mono*) (Lee 2002) and those in Italy ate seeds of field maple (*Acer campestre*) (Wauters et al. 2001). The lack of feeding signs on the above species (and also on other trees, which produce seeds consumed by squirrels, such as beeches (Moller 1983) or magnolias (Lee 2002)) could be explained by the short study interval. It is possible that study did not correspond to the year of abundant seed production for those species. It may also be likely that within understory vegetation, it was hard to notice cone remains or seeds. Amongst the species with no feeding signs of squirrels were also 11 fir species. In Japan, squirrels were foraging on the mentioned above Sakhalin pine (*Abies sachalinensis*) (Lee 2002) and in Russia on European silver fir (*Abies alba*) (Moller 1983). However, Rubino et al. (2012) suggested that because of high amount of tannins and terpenes in silver fir seeds, squirrels avoided those seeds.

Red squirrels strip bark from trunks and tree branches and eat cambium. It is more common in the case of larches, Scots pine, Norway spruce, silver birch (*Betula pendula*), European beech (*Fagus sylvatica*) and also sycamore maple (*Acer pseudoplatanus*). Such behaviour could also be connected with foraging on fungi growing under the bark (Krauze-Gryz, Gryz 2015). Squirrels also strip the bark whilst collecting phloem for construction of their dreys. In Poland, red squirrels often use basswood (*Tilia cordata*) phloem stripped from young branches for the construction of dreys (Krauze-Gryz D., personal observations). In the arboretum, red squirrels stripped peeling patches of bark from western red cedar (*T. plicata*), sawara cypress (*C. pisifera*) or dawn redwood (*M. glyptostroboides*). Their bark is elastic and easily peeled from the tree trunk, possibly being a good source of material for a drey construction.

6. Conclusions

1. Red squirrel density in the arboretum was higher than that in nearby commercial forests. It could result from the influx of individuals during the season with scarce food. Besides, rich food base (native tree species as well as numerous broadleaved and coniferous non-native species fruiting in different terms) could support higher densities of red squirrels.

2. The numbers of red squirrels observed in arboretum has been changing throughout the year. This could be explained by the population dynamics (reproduction), limited activity of squirrels during low temperature and also changing observation conditions throughout the year (vegetation density). However, it could also result from influx of animals to the area of the arboretum during the time of seed ripening (walnuts and hickories).

3. Red squirrels were foraging not only on tree species growing naturally in Poland but also on non-native tree species, such as those originating from North America. This shows flexibility of the studied species.

4. There were no feeding signs on tree species, which according to the literature, produce seeds possibly used by squirrels. This could be explained by short study period (study did not correspond to abundant seed production), a very young tree age, or difficulty in finding required feeding signs (small seeds, dense understory vegetation).

5. Soft, elastic, peeling tree bark was likely used by squirrels as a material for drey construction.

Conflict of interest

The authors declare the absence of potential conflicts.

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Authors' contribution

D.K-G – study conception, paper conception, statistical analyses, a figure, literature review, writing the paper; K.M. – refining the method of the field studies, field studies, data analysis; J.G. – study conception, field studies, writing the paper.

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