DOI: 10.21005/AAPZ2025.73.1.4

FOLIA POMERANAE UNIVERSITATIS TECHNOLOGIAE STETINENSIS
Folia Pomer. Univ. Technol. Stetin., Agric., Aliment., Pisc., Zootech. 2025, 374(73)1, 32–47

Received 9 Sep 2024
Revised 16 Oct 2024
Accepted 21 Oct 2024

Kornelia RÓŻANOWSKA

THE PROPOSAL FOR MONITORING OF RED SQUIRREL *SCIURUS VULGARIS* IN POLAND

Faculty of Animal Breeding, Bioengineering and Conservation, Warsaw University of Life Sciences – SGGW, Warsaw, Poland

Abstract. Red squirrel (*Sciurus vulgaris*) is an arboreal rodent which occurs naturally in Europe and Asia. The population trend of this species is marked as declining in many countries. In Poland red squirrel has been under partial protection since 2014 but there is low level of knowledge concerning local population size and trends, as there is no regular monitoring throughout the country. The purpose of this paper is to propose a monitoring method for red squirrel in Poland, which can help facilitate the acquisition of knowledge on the biology, population size and trends, state of the habitat, and the impact of this species on the environment in Poland. The method described in this paper consists of two types of indicators: state of the population (based on population density per 1 ha and co-occurrence of potentially conflict and invasive species of squirrels – grey squirrel, black squirrel and Pallas's squirrel) and state of the habitat (based on 4 individual components: wooded area, age of the stand, canopy closure, biomass of Norway spruce cones). Assessment of the indicators allows to determine whether the state of the habitat and/or population is favorable inadequate or bad for the monitored species. Regularly carried out monitoring can be a great help in understanding the dynamics of the red squirrel population in Poland and allow for an early response to threats to the species.

Key words: red squirrel, monitoring, threats to the species.

INTRODUCTION

The red squirrel (*Sciurus vulgaris*) is a species belonging to the order of rodents (*Rodentia*), the family of squirrels (*Sciuridae*), and the genus *Sciurus* (Lurz et al. 2005). Wilson and Reeder (2005) distinguish 23 subspecies of the red squirrel. As noted by Sidorowicz (1958), in Poland there are found squirrels from the subspecies *Sciurus vulgaris fuscoater* Altum, whose fur can be either light or dark in color.

In Poland, the red squirrel has been under partial protection since 2014 by virtue of the Regulation of the Minister of the Environment of October 6, 2014, on the protection of animal species (Dz.U. 2014 poz. 1348). This species is listed as Least Concern (LC) on the IUCN Red List of Threatened Species (Gazzard 2023). It holds the same status on the European

Corresponding author: Kornelia Różanowska, Faculty of Animal Breeding, Bioengineering and Conservation, Warsaw University of Life Sciences – SGGW, Jana Ciszewskiego 8, 02-786 Warsaw, Poland, e-mail: korneliarozanowska@gmail.com.

Red List. It is listed in Appendix III of the Bern Convention (Dz.U. 1996 nr 58 poz. 263). However, the population trend of this species is described as declining in countries such as the United Kingdom, Italy, Ireland, and Finland. Therefore, the implementation of threat and population monitoring is recommended (Gazzard 2023).

In practice, there are two groups of methods for monitoring squirrels: animal registration methods and genetic methods. Genetic monitoring based on DNA analysis from biological material samples can be a source of many important population-related information, such as genetic diversity and the degree of relationship between individual populations, the minimum number of individuals present in a given area, the size of individual territories, and the sex ratio (Hale et al. 2004; Ogden et al. 2005; Dozieres et al. 2012). Furthermore, genetic monitoring of the common squirrel in Poland will allow for the identification, based on the analysis of mitochondrial DNA, of the main haplotypes of native subpopulations, which can aid in better understanding the phylogeography of this species (Hale et al. 2004; Ogden et al. 2005).

The proposed source of genetic material is hair collected using hair traps. This method is recognized as an effective and non-invasive way to obtain genetic material from wild mammals (Sobkowiak et al. 2021). However, it should be noted that its effectiveness may depend on the ecological characteristics of the research environment, the duration of the study, and the species under study (Anile et al. 2012). It is also important to properly secure the samples, which should be stored in sterile envelopes or string bags and kept in a dry place. Ogden et al. (2005) suggest DNA extraction from hair bulb cells using the GeneluteTM Mammalian DNA Extraction kit with contamination control.

As proposed by Dozieres et al. (2012), the analysis should focus on the 516 base pair loop D fragment, corresponding to nucleotide positions 15464–15979 of the published full mitochondrial genome sequence of the common squirrel (GenBank accession number AJ238588), and the fragment should be amplified using PCR primers designed by Trizio et al. (2005), Lpro-SQL and SQR-SQR. The obtained DNA should be sequenced, and the acquired sequences subjected to analysis using the DNAsp5 program (Dozieres et al. 2012).

Unfortunately, the disadvantage of genetic methods is their laboriousness, high costs and requirements for appropriate reagents and laboratory equipment. For this reason, and due to the lack of regular country-wide monitoring studies of the red squirrel in Poland, this article aims to present a monitoring method based on the registration of animals and habitat condition research based on scientific studies and monitoring programs conducted in other countries.

SPECIES DESCRIPTION

Distribution

The red squirrel has the widest range of all tree squirrel species (Bosch and Lurz 2012), extending from the United Kingdom across Eurasia to China, Korea, and Japan (Sidorowicz 1958; Lurz et al. 2005). In Poland, the red squirrel occurs throughout the country, with most observations recorded in the central, southern, and northeastern parts of the country, and noticeably fewer in the northern and western parts, as shown in Fig. 1 (Atlas ssaków Polski). Gaps indicated in Atlas ssaków Polski are more likely caused by insufficient monitoring in those areas rather than absence of red squirrels.

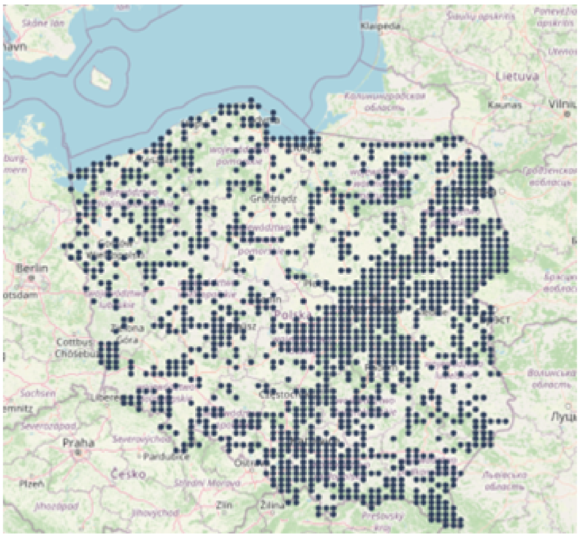

Fig. 1. Distribution of the red squirrel (*Sciurus vulgaris*) in Poland (source: Atlas ssaków Polski – https://www.iop.krakow.pl/Ssaki/gatunek/57)

Biology and ecology

In the red squirrel, there is no clear sexual dimorphism related to fur color or body size (Wiltafsky 1973). The head and body length of this species ranges between 180 and 332 mm, tail length between 130 and 222 mm, and ear length between 20 and 35 mm (Bosch and Lurz 2012). The body weight of this species falls within the range of 200–500 g, with seasonal weight changes observed, being highest in autumn and early winter, and lowest in early summer (Bosch and Lurz 2012). It also appears that seasonal weight fluctuations depend on the type of habitat, being less pronounced in coniferous forests where food availability is more predictable (Lurz and Lloyd 2000).

This species is characterized by a tail covered with long hairs, which makes up almost half of the animal's total length (Kowalski et al. 1984). The species has an arboreal lifestyle; it can jump and climb trees very well, although it sometimes descends to the ground, where it moves by jumping (Kowalski et al. 1984). *Sciurus vulgaris fuscoater* occurs in two main color variants – red and black, with these two color forms freely interbreeding to produce offspring with a dark color and a red stripe at the boundary of the dark fur on the back and sides of the body (Sokołowski 1947; Sidorowicz 1958; Kowalski et al. 1984). There are also individuals with a patterned back (Kowalski et al. 1984). As indicated by Romero et al. (2018), no albino red squirrels have been observed in Poland, but they have been reported in North America, Spain, the Netherlands, and the United Kingdom. It is noted that the black variant of squirrels occurs more frequently in the foothills and mountains (Zawidzka 1958). The fur on the back is usually dark, ranging from brown, through red and gray, to black, while the fur on the underside of the body is light, white, or creamy (Lurz et al. 2005).

Squirrels exhibit a seasonal coat, which is denser in winter. That is especially visible in the form of a bushy tail and 2.5–3.5 cm long hairs on the tips of the ears. In summer, the tail becomes thinner, and the ear tufts are significantly thinned or completely absent (Lurz et al. 2005).

Red squirrels are more active in coniferous forests than in deciduous forests (Wauters et al. 1992). In winter, red squirrels are active for a short time, which is probably an adaptation to reduce energy consumption by minimizing the period of heat loss (Tonkin 1983). In summer, the period of activity is more than twice as long as in winter, and there is usually a rest break around noon (Tonkin 1983). During this time, they retreat to shelters in the form of nests built in tree hollows from moss and lichens or to spherical nests built in tree crowns consisting of moss, grass, and twigs (Kowalski et al. 1984). They also sometimes take refuge in bird nests, which they modify by adding a roof (Kowalski et al. 1984).

The daily summer activity of squirrels starts at dawn and ends long after dusk, while in winter, it starts at sunrise and ends before the warmest part of the day (Tonkin 1983; Wauters et al. 1992). Squirrels spend most of their active time foraging, which constitutes up to 82% of their monthly activity, with the peak of food-gathering activity occurring in September (Tonkin 1983; Wauters et al. 1992). As described by Kowalski et al. (1984), in autumn, before the upcoming winter, squirrels begin to store food, mainly acorns and nuts, by burying them in the ground, hiding them in tree hollows or crevices. They also store mushrooms by hanging them on branches.

Low temperatures do not seem to affect squirrel activity (Tonkin 1983), but high temperatures above 26 degrees Celsius cause squirrels to cease activity and rest during the heat (Saint-Girons 1966; Purroy and Rey 1974). Squirrels are active during precipitation if it is not too intense (Tonkin 1983).

The red squirrel is an opportunistic species characterized by great flexibility in its diet (Bosch and Lurz 2012). Squirrels forage both in tree canopies, on tree branches, and on the forest floor, with the time spent in each layer dependent on the type of habitat, season, and food availability, but they mostly lead an arboreal lifestyle (Bosch and Lurz 2012). One squirrel consumes 35 grams of food per day in winter and up to 80 grams in summer (Kowalski et al. 1984).

The primary diet of the red squirrel consists mainly of plant food, i.e., seeds of coniferous and deciduous trees, buds, shoots, flowers, young tree bark, mushrooms, and berries (Kowalski et al. 1984). Plant food is supplemented by food of animal origin, such as insects, eggs, and bird nestlings (Kowalski et al. 1984). The preferred food base of squirrels includes seeds of trees, especially Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), Serbian spruce (*Picea omorika*), Douglas fir (*Pseudotsuga menziesii*), larch (*Larix sp.*), European yew (*Taxus baccata*), Scots pine (*Pinus sylvestris*), and shore pine (*Pinus contorta*) (Bosch and Lurz 2012).

The breeding season of the red squirrel begins in late February and March and ends in July (Kowalski et al. 1984). During the season, a female has one to three litters, with each litter averaging 3 to 5 young, sometimes up to 10 (Kowalski et al. 1984). After about 38 days of pregnancy, the young are born naked and blind, and after about 9 weeks, they become independent, reaching sexual maturity after a year (Kowalski et al. 1984).

Reproductive success is most often achieved by older males with higher body mass, who offer females protection from danger and engage in courtship by chasing, which can last for several hours (Wauters et al. 1990). In the Polish population, the sex ratio is close to 1:1 (Kowalski et al. 1984).

Outside the breeding season, red squirrels are solitary (Kowalski et al. 1984). Among males, there is a dominance hierarchy that is not always linear (Wauters et al. 1990).

In Poland, red squirrels are found in deciduous and coniferous forests, as well as in parks and gardens, including those located in cities (Kowalski et al. 1984; Babińska-Werka and Żółw 2008). As noted by Babińska-Werka and Żółw (2008), red squirrels are more numerous in parks located in the center of Warsaw than in suburban parks, with more than a twofold increase in their density in the Łazienki Królewskie Park over the past 50 years. In studies conducted in parks in Wroclaw, higher squirrel densities were observed in larger parks with older tree stands, located 2–7 km from the city center (Kopij 2014).

The optimal habitat for red squirrels in natural conditions is forests with areas ranging from 2000 to 5000 hectares, although this species can also be found in much smaller forests of less than 100 hectares (Lurz et al. 2005). The literature describes the range of this species' occurrence as between 1.5 hectares to 13.4 hectares (Corbet and Southern 1977; Wauters and Dhondt 1986). Typical density ranges from less than 0.1 individual to 1.5 individuals per hectare (Gurnell and Wauters 1999).

Red squirrels prefer foraging in areas near forest edges, which are characterized by lower understory density and high canopy density (Dylewski et al. 2021). This is likely related to the greater production of cones by coniferous trees growing at the forest edges compared to those growing in the forest interior (Phillipson 1987). High tree canopy density also greatly influences habitat use by red squirrels, as it facilitates free movement and provides protection from predation (Flaherty et al. 2012).

THREATS

Predators. In Poland, the main natural predators of squirrels are birds of prey and martens (Kowalski et al. 1984). Red squirrels also fall victim to weasels, foxes, wildcats, certain species of owls, birds of prey, as well as domestic cats and dogs (Lurz et al. 2005). It is noted that in urban areas, the domestic cat is one of the most significant predators affecting the red squirrel population (Margis and Gurnell 2002).

A significant threat to red squirrel populations is habitat fragmentation, as this species prefers large forest areas (Verboom and van Apeldoorn 1990).

Grey squirrel. The decline in the red squirrel population in the United Kingdom and Italy is due to competition with the invasive grey squirrel (*Sciurus carolinensis*), introduced from North America in the 19th century (Bertolino 2008). In Poland, this species has not yet been observed, but as noted by Krauze-Gryz and Gryz (2012), the probability of a stable population being established by two individuals of this species is at least 50%, and the arrival of this species in Poland is a matter of a few decades. An additional threat posed by grey squirrels is the transmission of the squirrelpox virus (SQPV), which is deadly to red squirrels and accelerates the displacement of the native species by up to 25 times (Rushton et al. 2006; Carroll et al. 2008; Krauze-Gryz and Gryz 2012). For this reason, the invasiveness of this species has been rated as moderately invasive (Krauze-Gryz et al. 2018a).

The grey squirrel (*Sciurus carolinensis*) can be distinguished from the red squirrel primarily by its size, being on average one-third larger (Krauze-Gryz and Gryz 2012). Unlike the red squirrel, the grey squirrel lacks prominent ear tufts (Krauze-Gryz and Gryz 2012). The fur of the grey squirrel is typically grey, although individuals can also be white, black, or red (Lehtinen et al. 2020).

These two species compete for resources – grey squirrels more efficiently utilize acorns as a food source, especially in deciduous forests dominated by oak trees (Kenward et al. 1998; Wauters et al. 2005). Other tree species that give grey squirrels an advantage in foraging include beech, chestnut, sycamore, and hazel (Bosch and Lurz 2012). Additionally, grey squirrels have been observed stealing food caches from native tree squirrels (Wauters et al. 2002). This competition leads to weight loss in red squirrels, reduces their reproductive success, and can ultimately cause local extinctions of the species (Gurnell et al. 2004; Wauters et al. 2005).

In Poland, the grey squirrel is listed in the Regulation of the Minister of the Environment of September 9, 2011 (Dz. U. 2011 Nr 210 poz. 1260) among species that, if released into the environment, could threaten native species. Therefore, importing this species into the country, keeping it, breeding it, reproducing it, or selling it requires the approval of the General Director for Environmental Protection (Dz. U. 2004 Nr 92 poz. 880). Nonetheless, as noted by Krauze-Gryz and Gryz (2012), acquiring a grey squirrel in Poland is not difficult, increasing the risk of its introduction into the environment.

Black squirrel. Another potentially conflict-prone species for the native red squirrel is the black squirrel (*Sciurus niger*), which is 3–4 times larger than the native species (Koprowski 1994). Due to competition for resources, this species has negatively impacted populations of native North American squirrels and has displaced the grey squirrel (*Sciurus carolinensis*) in some areas of California (Geluso 2004; Muchlinski et al. 2009; Clayton et al. 2015; Garcia and Muchlinski 2017). Additionally, the black squirrel is a carrier of viral diseases, bacterial infections, and parasites, such as SQFV (squirrel fibrima virus) and the nematode *Strongyloides robustus*, which pose a threat to the red squirrel (Wilcoxen et al. 2015). For these reasons, the invasiveness of this species has been classified as moderately invasive (Krauze-Gryz et al. 2018b).

Pallas's squirrel. Another species whose presence in Poland could negatively impact the red squirrel population is the Pallas's squirrel (*Callosciurus erythraeus*). However, this species naturally inhabits tropical and subtropical forests, moist temperate forests, and green mountain deciduous forests (Duckworth et al. 2017; Mazzamuto et al. 2017). Despite this, the Pallas's squirrel is resistant to harsh winters and, in European conditions, settles in deciduous, mixed, and coniferous forests (Bertolino and Lurz 2011; Dozieres et al. 2015).

Due to these reasons, the invasiveness of this species has been classified as low (Krauze-Gryz et al. 2018c).

METHOD – CONCEPT OF MONITORING

In Poland, there is no continuous monitoring of the red squirrel population, a species considered an important factor in the dispersal of plants whose seeds they bury for storage (Zhang et al. 2020). For this reason, the status of their population is unknown, which prevents active conservation efforts for this species. This is particularly problematic in the context of reports of declining numbers of this species in European countries (Gazzard 2023). It poses a threat by hindering a swift response in case invasive species, such as the grey squirrel (*Sciurus carolinensis*), appear in Poland.

A monitoring program has been proposed with the main goal of tracking the status of the common squirrel population across the country. Additionally, this monitoring could involve identifying areas where the common squirrel occurs and tracking changes in known locations based on selected environmental factors, which, according to various studies, influence the density of common squirrel individuals.

The adopted monitoring concept may be subject to changes in the future due to new scientific reports related to the species' ecology and based on the experiences gained from conducting the monitoring in subsequent years.

RESULTS

Indicators and assessment of the conservation state of the species

In the case of monitoring the common squirrel, it is proposed to assess habitat quality based on a composite indicator that reflects the habitat preferences characteristic of this species.

The habitat condition indicator is determined for the area selected for visual transects, i.e., 0.2 hectares of transect area for every 20 hectares of the monitored area, excluding the component "wooded area", which pertains to the total area, and the component "biomass of Norway spruce cones".

Indicators of the state of the population status and habitat condition are presented and described in the table (Table 1). The valorization of individual indicators is shown in the next tables (Table 2 and Table 3).

Table 1. Indicators of the population status and habitat condition for the red squirrel (*Sciurus vulgaris*)

Indicator	Measurement	Method
Population		
Population density	number of individuals N per ha	an indicator determined based on the number of individuals observed during visual transects
Components of the habitat indicator		
Wooded area	ha	designation of an uninterrupted wooded area
Age of the stand	descriptive component	determining the age of the tree stand in the monitored area
Canopy closure	%	estimation of tree crown cover based on digital photographs
Biomass of Norway spruce cones	mass of Norway spruce cones kg per ha	indicators' determination based on the biomass of cones per hectare of the monitored area

Table 2. Valorization of habitat indicator components for the red squirrel (*Sciurus vulgaris*)

Component of the habitat indicator/ score	0	0,5	1,0
Wooded area	<2 ha	2–10 ha	>ha
Age of the stand [years]	younger age classes (<80)	mature stand (80–100)	old-growth (>100)
Canopy closure	<60%	60–70%	>70%
Biomass of Norway spruce cones	<330 kg/ha	330–770 kg/ha	>770 kg/ha

Table 3. Valorization of the population status indicator and the composite habitat indicator for the red squirrel (*Sciurus vulgaris*)

Indicator/evaluation	FV	U1	U2
Population			
Population density	>0,75 individuals per hectare	<0,075 individuals per hectare	complete lack of observed individuals
Conflict and potentially invasive species	Complete lack of grey squirrels, black squirrels and Pallas's squirrels		presence of grey squirrel, black squirrel and/or Pallas's squirrel
Components of the habitat indicator	≥3	2–2,5	≤1,5

FV (favorable) – optimal population status and/or habitat conditions; U1 (unfavorable – inadequate) – suboptimal but not critically endangered population status and/or habitat conditions; U2 (unfavorable – bad) – poor population status and/or habitat conditions, may require immediate conservation efforts.

Assessment of the population state

The final assessment of population status indicator is equal to evaluation of population density as shown in Table 3. In case of the presence of a grey squirrel (*Sciurus carolinensis*), black squirrel (*Sciurus niger*) and/or Pallas's squirrel (*Callosciurus erythraeus*) assessment of the state of the population should be marked as U2 (unfavorable – bad).

Assessment of the habitat condition

The assessment of the composite habitat quality indicator directly correlates with the evaluation of habitat condition. This composite habitat condition indicator is calculated as the sum of points from individual habitat quality indicators. The scoring thresholds for this indicator are as follows: ≥3.0 – FV; 2.0 – 2.5 – U1; ≤ 1.5 – U2.

Protection perspectives

Assessment of species conservation prospects involves forecasting the population status and habitat conditions over the next 10–15 years, considering current impacts and anticipated threats that may affect the future population and habitat at the study site. The prospects for maintaining the species in a specific habitat and its conservation are considered favorable (FV) only at sites where the density of Eurasian red squirrels exceeds 0.75 individuals per hectare, and where habitat conditions favor population occurrence. This includes continuous wooded areas on monitored habitats, mature tree cover allowing for free movement between tree canopies due to their compact nature, and the quality of the food base, exemplified by the biomass of Norway spruce cones. Inadequate (U1) or bad (U2) conservation prospects are linked to habitat mismatches with the preferences of Eurasian red squirrels and other impacts such as predation pressure. The lowest conservation prospects will be for habitats where invasive and conflicting species occur, which are key indicators due to their significant ecological pressure and disease transmission (Krauze-Gryz and Gryz 2012; Krauze-Gryz et al. 2018a, 2018b, 2018c).

Overall assessment

The conservation status of the species at a site should be determined based on assessments of population status, habitat conditions, and conservation prospects at that site, with the lowest of these three assessments determining the overall status.

DISCUSSION

The choice of monitoring areas and their suggested size

The monitoring should cover sites representing all regions of occurrence of the red squirrel. A significant methodological issue is the presence of inventory gaps. So far, there has been no nationwide monitoring of the red squirrel. Therefore, the first step in planning would be to designate potential habitats for the red squirrel, which initially could be based on previous reports of species occurrence, confirmed by experts. For this purpose, hair traps or camera traps could be used as cost-effective and time-efficient methods. In Shannon et al. (2023), a strong correlation was observed between the number of red squirrels captured and the number of photos taken by camera traps in a given area. This method is recommended for its low cost and minimal invasiveness. However, in areas with low population density of the species, it may be less accurate, but can still provide information on the relative rarity of the species. It can also be used to detect the presence of invasive species and provides information on habitats preferred by red squirrels.

For practical purposes, a monitoring site can be considered as a forest stand within a forest complex or urban park where the red squirrel has been observed. For such sites, 0.2 hectares of transects are designated for every 20 hectares of area, and a representative area of 14 m × 14 m is used to estimate the biomass of Norway spruce cones.

The density of individuals

An accurate assessment of the population size of the red squirrel would be very difficult to achieve due to the use of very costly, labor-intensive, and invasive methods such as capture-mark-recapture and trapping methods. Therefore, a less precise but less invasive and less costly method is proposed, which involves setting up visual transects, counting observed red squirrels, and estimating the density of individuals per hectare of the study area.

For this purpose, according to Mróz (2015), it is proposed to designate a transect area of 0.2 hectares, ideally 10 meters wide and 200 meters long, for every 20 hectares of the total study habitat area. Then, based on the formula proposed by Gurnell et al. (2009), the density should be estimated. The formula looks as follows:

$$d = \frac{n}{2wl}$$

Where: d – density of individuals per m²; n – number of observed individuals; l – length of the transect; w – width of the transect.

The result obtained should be provided as the number of individuals per hectare. The assessment of individual density per hectare was established based on research results conducted by Gurnell and Wauters (1999) and Kopij (2014): density >0.75/ha – favorable state; <0.75/ha – inadequate state; total absence of individuals/ha – bad state.

Cardinal indicator. Additionally, a cardinal indicator in the form of observing the presence of invasive and conflicting species relative to the red squirrel has been determined. These include the grey squirrel (*Sciurus carolinensis*), the black squirrel (*Sciurus niger)*, and the Pallas's squirrel (*Callosciurus erythraeus)*. Noting the presence of any of these species in the monitored area results in a U2 rating indicating a poor habitat state.

It is also recommended to use hair traps as a method of collecting material for genetic monitoring and for detecting the presence of the red squirrel (*Sciurus vulgaris*) and the grey squirrel (*Sciurus carolinensis*). This technique is cost-effective and does not require a large amount of time. Gurnell et al. (2009) recommend preparing hair traps using plastic pipes with a diameter of 65 mm and a length of 300 mm, with a plastic or wooden block attached

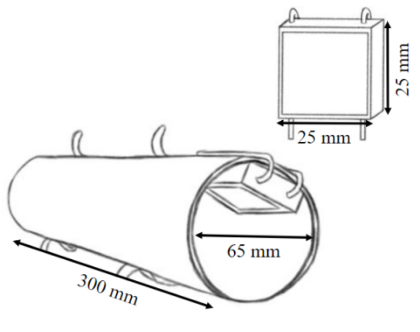

Fig. 2. Diagram of the hair trap model (bottom) and wooden block with affixed adhesive tape (top)

approximately 3 cm from any light source of the device, onto which double-sided adhesive tape is affixed. Such prepared traps should be mounted using wire on tree branches. Gurnell et al. (2009) recommend installing up to 20 prepared hair traps per study area at distances of 100 m to 200 m in a line or grid pattern. They also recommend using bait such as sunflower seeds, peanuts, or corn. Blocks from traps should be collected at regular intervals, for example, every 3, 7, or 14 days. The construction of the hair trap is shown in Fig. 2.

Hairs collected using adhesive tape can be used for species identification or genetic monitoring. Gurnell et al. (2009) recommend the following method for squirrel species identification: place the adhesive tape with the hairs in warm water containing detergent and soak them overnight. Then, collect at least 10 representative hairs from each tape fragment, each hair being at least 1.5 mm long (shorter hairs might belong to mice and voles). Next, immerse the hairs in a solution of Indian ink and water in a 5:1 ratio. Prepared hairs should be examined under a light microscope at a recommended magnification of ×400. The widest part of each hair should be compared. Hairs with a continuous dark line along the edge will belong to the red squirrel. Furthermore, the cross-section of red squirrel hairs will have a dumbbell shape or be concave, whereas the cross-section of the grey squirrel hairs will be round, as shown in Fig. 3.

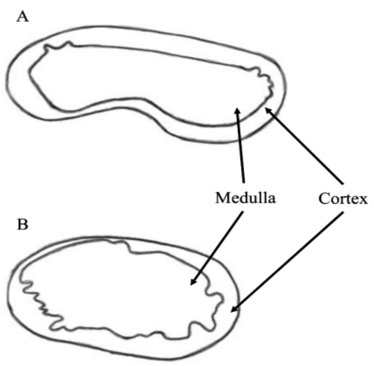

Fig. 3. A schematic cross-section of the hair of two squirrel species, showing the medulla and cortex. The cross-section of the red squirrel's hair (A) is concave, while the cross--section of the grey squirrel's hair (B) is round

The habitat condition indicator

Wooded area. It is necessary to determine the continuous, non-fragmented surface area of the selected forest complex or urban park. Estimating the area is feasible using satellite data, aerial photographs from publicly available sources such as Google Earth, as well as forest maps and plans available in Forest Management Plans (FMP) and Conservation Tasks Plans for Natura 2000 areas. This information can be obtained from the Forest Data Bank (BDI) for State Forests. Then, using software tools, estimate the size of the non-fragmented area by marking the boundaries of forested areas. Area fragmentation is considered when there are public roads, rivers, and fields that disrupt the continuity of the wooded area. In the case of forest complex or park fragmentation, only the largest fragment area is considered.

Age of the stand. It is essential to determine the dominant age of the forest stand in the monitored habitat of the red squirrel. Older trees create a more favorable environment for this species. The age of trees in specific forest compartments can be found in the Forest

Management Plan of the relevant forest district for areas managed by State Forests, or in the Conservation Tasks Plans for Natura 2000 areas. This information can be obtained from the Forest Data Bank (BDI) for State Forests. It is also possible to conduct an assessment independently by assuming random sample areas in the stand and estimating the age of individual trees, which requires expert knowledge.

Canopy closure. It is essential to determine the approximate percentage of tree crown cover, indicating their closure. According to Myczko et al. (2014), the tree crown cover should be estimated based on up to 30 crown photographs taken in a similar manner, vertically, aiming at tree crowns. Then, transform the color of the obtained photos into black-and-white mode and estimate the percentage of crown closure based on the average ratio of black to white spaces from all photos taken in the area under study.

From the data obtained by Dylewski et al. (2021), it can be inferred that the higher the tree crown closure, the greater the population density of the red squirrel in the habitat. For this reason, the evaluation values of this component were determined to be: <60% – bad state; 60–70% – inadequate state; >70% – favorable state.

Biomass of Norway spruce cones. The occurrence of coniferous trees favors the presence of the red squirrel because they produce cones, an important component of the diet of this species (Verboom and van Apeldoorn 1990; Lurz and Lloyd 2000). The assessment of the component related to the biomass of Norway spruce cones, as determined by Dylewski et al. (2021), should be carried out by designating an area measuring 14 m × 14 m, where tree measurements are made according to the formula developed by Finer (1989), presented as follows:

$$\mathrm{M_{Ns}} = \frac{(\mathrm{dbh}^{a_1} \times \mathrm{cr}^{a_2})}{1000}$$

Where: M_{Ns} – biomass of Norway spruce cones per tree [kg]; dbh – diameter at breast height [cm]; cr – tree crown ratio; a_1 – 1.2358; a_2 – 4.7864.

Then, average the collected data and multiply it by the estimated number of common spruce trees per 1 ha of the study area. The number of spruce trees per 1 ha can be obtained by multiplying the number of spruce trees observed in the 14 m × 14 m area by a multiplier equal to 51.

Thus, the estimated biomass of Norway spruce cones per 1 ha of the study area is obtained.

From the data obtained by Dylewski et al. (2021), it can be inferred that the biomass of cones less than approximately 30 kg per 14 m × 14 m area does not favor feeding by red squirrels in that area. The number of gnawed cones increases proportionally with the increase in biomass of common spruce cones starting from approximately 30 kg per study area. A significant increase in the number of gnawed cones occurs when the biomass of cones per study area reaches approximately 70 kg.

Based on these results, evaluation values for this component were calculated as follows: <300 kg/ha – bad state (0 points); 300–770 kg/ha – inadequate state (0.5 points); >770 kg/ha – favorable state (1 point).

As noted by Dylewski et al. (2021), a disadvantage of this method is the lack of adjustments for mast years and non-mast years, as well as fluctuations in cone production between individual trees and years. However, as they emphasize, estimating cone biomass provides crucial information about the quality and use of the environment by red squirrels.

Date, frequency and technical requirements

Monitoring the population of the red squirrel and its habitats in Poland is proposed to be conducted in the autumn period, preferably around September, between 8 AM and 4 PM, when the peak activity for foraging occurs and the observed number of individuals is highest (Tonkin 1983; Wauters et al. 1992; Babińska-Werka and Żółw 2008). In case of heavy rainfall, strong winds, or temperatures above 26 degrees Celsius, the monitoring should be postponed, as these conditions interrupt squirrel activity and cause them to seek shelter.

It is recommended to conduct the monitoring optimally once every 3 years, but no less frequently than every 6 years.

Equipment and materials necessary for field monitoring:

– GPS receiver,
– scale,
– measuring tape with a minimum length of 20 meters,
– notebook and pen,
– calculator,
– camera (for illustrative documentation of the site),
– minimum of 20 pre-prepared hair traps,
– bait such as sunflower seeds, peanuts, or corn kernels,
– metal wire (for mounting hair traps),
– ladder,
– clothing suitable for field and weather conditions.

Equipment and materials necessary for laboratory monitoring:

– light microscope with a magnification of approximately × 400,
– solution of detergent with water,
– solution of Indian ink with water in a ratio of 4:1,
– tweezers.

CONCLUSION

The red squirrel is partially protected in Poland, but no specific actions are currently being taken to protect it. There is also very limited information about where the species is found in the country. Setting up regular monitoring across Poland would help us better understand the red squirrel's distribution and allow us to develop management plans to address potential threats, such as the likely arrival of the invasive grey squirrel or population declines. This proposal is the first step toward creating a monitoring program for the red squirrel in Poland, and the approach should be improved as more data is gathered.

REFERENCES

Anile S., Arrabito C., Mazzamuto M.V., Scornavacca D., Ragni B. 2012. A non-invasive monitoring on European wildcat (*Felis silvestris silvestris* Schreber, 1777) in Sicily using hair trapping and camera trapping: does it work? Hystrix It. J. Mamm. 23(3), 45–50. DOI: 10.4404/hystrix-23.2-4657.

Babińska-Werka J., Żółw M. 2008. Urban populations of the Red Squirrel (*Sciurus vulgaris*) in Warsaw. Ann. Zool. Fennici 45(4), 270–276. DOI: 10.5735/086.045.0405.

Bertolino S. 2008. Introduction of the American grey squirrel (*Sciurus carolinensis*) in Europe: a case study in biological invasions. Curr. Sci. 95, 903–906.

Bertolino S., Lurz P.W. 2011. *Callosciurus* squirrels: worldwide introductions, ecological impacts and recommendations to prevent the establishment of new invasive populations. Mammal Rev. 43(1), 22–33. DOI: 10.1111/j.1365-2907.2011.00204.x.

Bosch S., Lurz P.W. 2012. The Eurasian Red Squirrel *Sciurus vulgaris*. Magdeburg: Westarp-Wiss.

Carrol B., Gurnell J., Nettleton P., Sainsbury A.W. 2008. Epidemics of squirrelpox virus disease in red squirrels (*Sciurus vulgaris*): temporal and serological findings. Epidemiol. Infect. 137(2), 257–265. DOI: 10.1017/s0950268808000836.

Clayton S.C., Muchlinski A.E., Torres E. 2015. Multiple introductions of the eastern fox squirrel (*Sciurus niger*) in California. Mitochondrial DNA 26(4), 583–592. DOI: 10.3109/19401736.2013.878903.

Corbet G.B., Southern H.N. 1977. The handbook of British mammals. London: Blackwell Scientific Publications.

Dozieres A., Chapuis J.L., Thibault S., Baudry E. 2012. Genetic structure of the French red squirrel populations: Implication for conservation. PLOS One 7, 10, e47607.

Dozieres A., Pisanu B., Kamnova S., Bastelica F., Gerriet O., Chapuis J.L. 2015. Range expansion of Pallas's squirrel (*Callosciurus erythraeus*) intriduced in southern France: Habitat suitability and space use. Mamm. Biol. 80(6), 518–526. DOI: 10.1016/j.mambio.2015.08.004.

Duckworth J.W., Timmins R.J., Molur S. 2017. Callosciurus erythraeus, in: The IUCN Red List of Threatened Species. e.T3595A2225435.

Dylewski Ł., Jagodziński A.M., Tomaś Ł., Myczko Ł. 2021. Forest stand structure and cone crop affect winter habitat use by Eurasian red squirrel (*Sciurus vulgaris*). For. Ecol. Manag. 502, 1–7. DOI: 10.1016/j.foreco.2021.119705.

Flaherty S., Patenaude G., Close A., Lurz P.W. 2012. The impact of forest stand structure on red squirrel habitat use. Forestry 85(3), 437–444. DOI: 10.1093/forestry/cps042.

Finér L. 1989. Biomass and nutrient cycle in fertilized and unfertilized pine, mixed birch and pine and spruce stands on a drained mire. Acta For. Fenn. 208, 1–35. DOI: 10.14214/aff.7655.

Garcia R.B., Muchlinski A.E. 2017. Range expansion of the Eastern Fox Squirrel within the Greater Los Angeles Metropolitan Area (2005-2014) and projections for continued range expansion. Bull. South. Calif. Acad. Sci. 116(1), 33–45.

Gazzard A. 2023. Sciurus vulgaris. The IUCN Red List of Threatened Species. e. T221730864A221731049.

Geluso K. 2004. Westward expansion of the eastern fox squirrel (*Sciurus niger*) in northeast New Mexico and sountheastern Colorado. Southeast. Nat. 49(1), 111–116. DOI: 10.1894/0038-4909(2004)049%3C0111:WEOTEF%3E2.0.CO;2.

Gurnell J., Lurz P.P., Pepper H. 2009. Practical techniques for surveying and monitoring squirrels. Forestry Commision Practice Note 11. Edinburgh: Forestry Commision.

Gurnell J., Wauters L. 1999. *Sciurus vulgaris*, in: The Atlas of European Mammals. Eds. A.J. Mitchell-Jones, G. Amori, W. Bogdanowicz, B. Kryštufek, P.J.H. Reijnders, F. Spitzenberger, M. Stubbe, J.B. Thissen, V. Vohralík, J. Zima. London: Academic Press, 180–182.

Gurnell J., Wauters L.A., Lurz P.W., Tosi G. 2004. Alien species and interspecific competition: effects of introduced eastern squirrels on red squirrel population dynamics. J. Anim. Ecol. 73(1), 26–35. DOI: 10.1111/j.1365-2656.2004.00791.x.

Hale M.L., Lurz P.W., Wolff K. 2004. Patterns of genetic diversity in the red squirrel (*Sciurus vulgaris* L.): Footprints of biogeographic history and artificial introductions. Conserv. Genet. 5, 167–179. DOI: 10.1023/B:COGE.0000030001.86288.12.

Instytut Ochrony Przyrody PAN. 2010. Atlas ssaków Polski, https://www.iop.krakow.pl/Ssaki/gatunek/57 [in Polish].

Kenward R.E., Hodder K.H., Rose R.J., Walls C.A. 1998. Comparative demography of red squirrels (*Sciurus vulgaris*) and grey squirrels (*Sciurus carolinensis*) in deciduous and conifer woodland. J. Zool. 244(1), 7–21. DOI: 10.1111/j.1469-7998.1998.tb00002.x.

Konwencja o ochronie gatunków dzikiej flory i fauny europejskiej oraz ich siedlisk, sporządzona w Bernie dnia 19 września 1979 r. DzU z 1 stycznia 1996 r., nr 58, poz. 263 [in Polish].

Kopij G. 2014. Distribution and abundance of the Red squirrel Sciurus vulgaris in an urbanised environment. Acta Mus. Siles. Sci. Natur. 63(3), 255–262. DOI: 10.2478/cszma-2014-0022

Koprowski J.L. 1994. Sciurus niger. Mammalian species, 479, 1–9.

Kowalski K., Pucek Z., Ruprecht A.L. 1984. Rząd: Gryzonie – Rodentia, in: Klucz do oznaczania ssaków Polski. Red. Z. Pucek. Warszawa: PWN, 46–91 [in Polish].

Krauze-Gryz D., Gryz J. 2012. Wiewiórka szara *Sciurus carolinensis* w Polsce: science fiction czy realne zagrożenie? Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej 33, 4, 327–334 [in Polish].

Krauze-Gryz D., Romanowski J., Solarz W. 2018b. Karta informacyjna gatunku *Sciurus niger*, 1–7 [in Polish].

Krauze-Gryz D., Romanowski J., Solarz W. 2018c. Karta informacyjna gatunku *Callosciurus erythraeus*, 1–7 [in Polish].

Krauze-Gryz D., Solarz W., Okarma H. 2018a. Karta informacyjna gatunku *Sciurus carolinensis*, 1–7 [in Polish].

Lehtinen R.M., Carlson B.M., Hamm A.R., Riley A.G., Mullim M.M., Gray W.J. 2020. Dispatches from the neighborhood watch: Using citizen science and field survey data to document color morph frequency in space and time. Ecol. Evol. 10(3), 1526–1538. DOI: 10.1002/ece3.6006.

Lurz P.W., Gurnell J., Magris L. 2005. *Sciurus vulgaris*. Mamm. Spec. 769, 1–10.

Lurz P.W., Lloyd A.J. 2000. Body weights in grey and red squirrels: do seasonal weight increases occur in conifer woodland? J. Zool. 252(4), 539–543. DOI: 10.1111/j.1469-7998.2000.tb01237.x.

Margis L., Gurnell J. 2002. Population ecology of the red squirrel (*Sciurus vulgaris*) in a fragmented woodland ecosystem on the Island of Jersey, Channel Islands. J. Zool. 256(1), 99–112. DOI: 10.1017/S0952836902000134.

Mazzamuto M.V., Bisi F., Wauters L.A., Preatoni D.G., Martinoli A. 2017. Interspecific competition between alien Pallas's squirrels and Eurasian red squirrels reduces density of the native species. Biol. Invasions 19(2), 723–735. DOI: 10.1007/s10530-016-1310-3.

Mróz W. (red.). 2015. Monitoring siedlisk przyrodniczych. Przewodnik metodyczny. Część czwarta. Warszawa: Biblioteka Monitoringu Środowiska [in Polish].

Muchlinski A., Stewat G., KIng J., Lewis S. 2009. Documentation of replacement of native western gray squirrels by introduced eastern fox squirrels. Bull. Southern Calif. Acad. Sci. 108(3), 160–162. DOI: 10.3160/0038-3872-108.3.160.

Myczko Ł., Rosin Z.M., Skórka P., Tryjanowski P. 2014. Urbanization level and woodland size are major drivers of woodpecker species richness and abundance. PLoS ONE 9(4), 1–10. DOI: 10.1371/journal.pone.0094218.

Ogden R., Shuttleworth C., McEwing R., Cesarini S. 2005. Genetic management of the red squirrel, *Sciurus vulgaris*: a practical approach to regional conservation. Conserv. Genet. 6, 511–525. DOI: 10.1007/s10592-005-9006-8.

Phillipson J.J. 1987. A review of coning and seed production in Picea sitchensis. Proc. R. Soc. Edin. B. 93(1-2), 183–195. DOI: 10.1017/S0269727000006382.

Purroy F.J., Rey J.M. 1974. Estudio ecologico y siste- matico de la ardilla (*Sciurus vulgaris*) en Navarra. I. Distribución, densidad de poblaciones, alimentación, actividad diaria y annual [Ecological and systematic study of red squirrel (*Sciurus vulgaris*) in Navarra. I. Distribution, population density, feeding, and diurnal and annual activity]. Bol. Estac. Cent. Ecol. 3(5), 71-82 [in Spanish].

Romero V., Racines-Marquez C.E., Brito M.J. 2018. A short review and worldwide list of wild albino rodents with the first report of albinism in *Coendou rufescens* (Rodentia: Erethizontidae). Mammalia 82(5), 509–515. DOI: 10.1515/mammalia-2017-0111.

Rozporządzenie Ministra Środowiska z 9 września 2011 r. w sprawie listy roślin i zwierząt gatunków obcych, które w przypadku uwolnienia do środowiska przyrodniczego mogą zagrozić gatunkom rodzimym lub siedliskom przyrodniczym. DzU z 9 września 2011 r., nr 210, poz. 1260 [in Polish].

Rozporządzenie Ministra Środowiska z dnia 6 października 2014 r. w sprawie ochrony gatunkowej zwierząt. DzU z 6 października 2014 r., poz. 1348 [in Polish].

Rushton S.P., Lurz P.W., Gurnell J., Nettleton P., Bruemmer C., Shirley M.D., Sainsbury A.W. 2006. Disease threats posed by alien species: the role of a poxvirus in the decline of the native red squirrel in Britain. Epidemiol. Infect. 134(3), 521–533. DOI: 10.1017/S0950268805005303.

Saint-Girons M.C. 1966. Le rythme circadien de l'activité chez les Mammifères holarctiques. Mém. Mus. Natl. Hist. Nat. 40(3), 1–86 [in French].

Shannon G., Valle S., Shuttleworth C.M. 2023. Capturing red squirrels (*Sciurus vulgaris*) on camera: A cost-effective approach for monitoring relative abundance and habitat preference. Ecol. Evol. 13(10), e10536. DOI: 10.1002/ece3.10536.

Sidorowicz J. 1958. Geographical varation of the red squirrel *Sciurus vulgaris* L. in Poland [Geographical variation of the squirrel *Sciurus vulgaris* L. in Poland]. Acta Theriol. 2(7), 141–157 [in Polish].

Sobkowiak M., Kochan J.I., Kruszyński W. 2021. Assessing the efficiency of using passive hair traps as a method for non-invasive sampling from European beavers (*Castor fiber* L.). J. Vertebr. Biol. 71, 21053. DOI: 10.25225/jvb.21053.

Sokołowski J. 1947. Owadożerne i gryzonie Gór Świętokrzyskich. Kosmos 65, 1–4 [in Polish].

Tonkin J.M. 1983. Activity patterns of the Red squirrel (*Sciurus vulgaris*). Mammal Rev. 13, 99–111. DOI: 10.1111/j.1365-2907.1983.tb00271.x.

Trizio I., Crestanello B., Galbusera P., Wauters L.A., Tosi G., Matthysen E., Hauffe H.C. 2005. Geographical distance and physical barriers shape the genetic structure of Eurasian red squirrels (*Sciurus vulgaris*) in the Italian Alps. Mol. Ecol. 14(2), 469–481. DOI: 10.1111/j.1365-294x.2005.02428.x.

Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody. DzU z 16 kwietnia 2004 r., nr 92, poz. 880 [in Polish].

Verboom B., van Apeldoorn R. 1990. Effects of habitat fragmentation on the red squirrel, Sciurus vulgaris L. Landsc. Ecol. 4(2), 171–176. DOI: 10.1007/BF00132859.

Wauters L.A., Dhondt A.A. 1986. Dichtheid en home ranges van een populatie eekhoorns Sciurus vulgaris L., 1758 in Belgie [Density and home ranges of a population of squirrels Sciurus vulgaris L., 1758 in Belgium]. Lutra 29, 243–260 [in Dutch].

Wauters L.A., Dhondt A.A., De Vos R. 1990. Factors affecting male mating success in red squirrels (*Sciurus vulgaris*). Ethology Ecol. Evol. 2(2), 195–204. DOI: 10.1080/08927014.1990.9525486.

Wauters L.A., Swinnen C., Dhondt A.A. 1992. Activity budget and foraging behaviour or red squirrels (Sciurus vulgaris) in coniferous and deciduous habitats. J. Zool. 227(1), 71–86. DOI: 10.1111/j.1469-7998.1992.tb04345.x.

Wauters L.A., Tosi G., Gurnell J. 2002. Interspecific competition in tree squirrels: do introduced grey squirrels (*Sciurus carolinensis*) deplete tree seeds hoarded by red squirrels (*S. vulgaris*)? Behav. Ecol. Sociobiol. 51, 360–367. DOI: 10.1007/s00265-001-0446-y.

Wauters L.A., Tosi G., Gurnell J. 2005. A review of the competitive effects of alien grey squirrels on behaviour, activity and habitat use of red squirrels in mixed, deciduous woodland in Italy. Hystrix 16, 27–40. DOI: 10.4404/hystrix-16.1-4340.

Wilcoxen T.E., Seitz J., Nuzzo J.T. 2015. Squirrel fibroma virus infection in an Eastern fox squirrel (*Sciurus niger*) from Sangamon County, Illinois. Trans. Ill. State Acad. Sci. 108, 27–28.

Wilson D.E., Reeder D.M. 2005. Mammal species of the world. A taxonomic and geographic reference. Baltimore: Johns Hopkins University Press.

Wiltafsky H. 1973. Die geographische Variation morphologischer Merkmale bei *Sciurus vulgaris* L., 1758. Ph.D. dissertation. Koln: Universitat zu Koln [in German].

Zawidzka E. 1958. Geographical distribution of the dark phase of the squirrel (*Sciurus vulgaris fuscoater* Altum) in Poland. Acta Theriol. 2(8), 159–174.

Zhang M., Su C., Lu C. 2020. Distribution of eight species of large-seeded pines and their primary animal seed-dispersers in China: match or mismatch? Advance 1–11. DOI: 10.22541/au.159741393.36268899.

PROPOZYCJA MONITORINGU WIEWIÓRKI POSPOLITEJ (*SCIURUS VULGARIS*) W POLSCE

Streszczenie. Wiewiórka pospolita (*Sciurus vulgaris*) jest nadrzewnym gryzoniem, który naturalnie występuje w Europie i Azji. W wielu krajach obserwuje się tendencję spadkową populacji tego gatunku. W Polsce wiewiórka pospolita znajduje się pod częściową ochroną od 2014 roku, jednak poziom wiedzy na temat jej lokalnej liczebności i trendów populacyjnych jest niski, ponieważ brakuje regularnego monitoringu w całym kraju. Celem niniejszej pracy jest zaproponowanie metody monitoringu wiewiórki pospolitej w Polsce, który może przyczynić się do zdobycia wiedzy na temat biologii, liczebności populacji i jej trendów, stanu siedliska oraz wpływu tego gatunku na środowisko w Polsce. Opisana metoda składa się z dwóch typów wskaźników: stanu populacji (opartego na zagęszczeniu osobników przypadających na 1 ha i współwystępowaniu potencjalnych gatunków konfliktowych i inwazyjnych – wiewiórki szarej, wiewiórki czarnej i wiewiórczaka rdzawobrzuchego) oraz stanu siedliska (opartego na czterech indywidualnych składowych: powierzchni zadrzewionego obszaru, wieku drzewostanu, zwarciu koron drzew oraz biomasy szyszek świerka pospolitego). Ocena wskaźników pozwala na określenie, czy stan siedliska i/lub populacji jest korzystny, niewystarczający czy zły dla monitorowanego gatunku. Regularnie przeprowadzany monitoring może znacznie pomóc w zrozumieniu dynamiki populacji wiewiórki pospolitej w Polsce i pozwolić na wczesną reakcję na zagrożenia dla tego gatunku.

Słowa kluczowe: wiewiórka pospolita, monitoring, zagrożenia dla gatunku.