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# How to Count the Uncountable? An Attempt at Wild Boar *Sus scrofa*, Linnaeus, 1758 Monitoring in an Urbanized Area

**Jakub Gryz [1], Karolina D. Jasińska [2], Michał Brach [3], Mateusz Jackowiak [4] and Dagny Krauze-Gryz [2,*]**

[1] Department of Forest Ecology, Forest Research Institute, Braci Leśnej 3, Sękocin Stary, 05-090 Raszyn, Poland; j.gryz@ibles.waw.pl
[2] Department of Forest Zoology and Wildlife Management, Institute of Forest Sciences, Warsaw University of Life Sciences WULS—SGGW, Nowoursynowska 159, 02-776 Warsaw, Poland; karolina_jasinska@sggw.edu.pl
[3] Department of Geomatics and Land Management, Institute of Forest Sciences, Warsaw University of Life Sciences WULS—SGGW, Nowoursynowska 159, 02-776 Warsaw, Poland; michal_brach@sggw.edu.pl
[4] Institute of Environmental Protection—National Research Institute, Słowicza 32, 02-170 Warsaw, Poland; mateusz.jackowiak@ios.gov.pl
* Correspondence: dagny_krauze_gryz@sggw.edu.pl

**Abstract:** In order to minimize human–wildlife conflicts, long-term and data-based management plans need to be developed. We aimed at assessing wild boar (*Sus scrofa*, Linnaeus, 1758) density within selected areas of Warsaw, the capital city of Poland. Wild boar abundance was estimated based on snow tracking conducted within 19 well-defined sectors, varying in habitat structure and location within the city. Moreover, in two forest reserves, wild boar population density was assessed with the use of camera traps and a random encounter model. The wild boar density index (n tracks/100 m/24 h) in Warsaw varied from 0 to 3.58 depending on the sector (0 to 4.0 ind./100 ha). In turn, it was 1.8 ind./100 ha for all the forested areas, which did not seem high compared to the other wild boar populations in Poland. The REM-derived estimates were higher than the snow-tracking-based estimates. Wild boars were mostly present in forests, especially those with oak stands, while the species was absent from central districts and mostly urbanized areas. We argue that the snow tracking method reflected the general distribution of wild boars across the city and in different habitats.

**Keywords:** random encounter model; snow tracking; urban area; density assessment; habitat use



**Citation:** Gryz, J.; Jasińska, K.D.; Brach, M.; Jackowiak, M.; Krauze-Gryz, D. How to Count the Uncountable? An Attempt at Wild Boar *Sus scrofa*, Linnaeus, 1758 Monitoring in an Urbanized Area. *Forests* **2024**, *15*, 1497. https://doi.org/10.3390/f15091497

Academic Editors: Alexey Andreychev and Todd Fredericksen

Received: 13 July 2024
Revised: 13 August 2024
Accepted: 16 August 2024
Published: 27 August 2024



## 1. Introduction

As cities expand, their impacts on natural ecosystems and the wildlife residing within them increase [1]. In general, increased urbanization leads to a loss in mammalian diversity [2]. Nevertheless, the use of urban areas by wildlife and urban species population numbers have increased over the years [3,4]. In general, an expansion of ungulates to new areas has been observed in Europe [5]. Indeed, wild boar (*Sus scrofa* Linnaeus, 1758) populations have grown steadily across Europe in the past few decades, resulting in more frequent human–wild boar conflicts [6–8]. This species occurs throughout a wide spectrum of habitats, including urban and suburban areas [6,9–13]. The impact of wild boars on economic interests may be diverse, including the risk of vehicle collisions and damage to crops and amenities (see [6]). Wild boars may also act as reservoirs for many important infectious diseases in domestic animals and also people [14,15]. Some animals that persist in urban environments demonstrate behaviors distinct from their non-urban counterparts [1]. For example, the flight distance of urban wild boars is shorter [16]; thus, wild boar–human encounters are more frequent than in non-urban areas. This may cause anxiety and fear of wild boar attacks or aggressiveness towards people or domestic animals [11,13,17,18].

In order to minimize human–wildlife conflicts, effective long-term management plans need to be developed [6,11]. Nevertheless, the management of wild boar populations

remains a challenge for scientists and city governors [7,11,17,19–23]. Also, no data-driven strategy for urban wild boars has been implemented in Warsaw.

To control ASF spread, the Polish Ministry of Agriculture and Rural Development issued a regulation to hunters to reduce the population density of wild boars across the country to the level of 0.1–0.5 individuals per 100 ha [24]. In the following years, this resulted in very intensive wild boar population control, with an increase from 100 to 200 thousand to as many as 350 thousand individuals being shot yearly in Poland [25]. According to the official hunting data, the wild boar population across Poland decreased from around 200–250 thousand individuals in 2013–2018 to 50–100 thousand individuals in the subsequent seasons, with no population rise being recorded [25]. Wild boar density estimation is difficult [7], and in Poland, the number of wild boars in hunting districts is mainly determined by hunters arbitrarily and is often guessed rather than scientifically estimated [26]. Thus, the real population abundance in hunting grounds in Poland and in urban areas, is unknown.

At the same time, media coverage of wild boars' presence in urban areas and their increasing abundance in Warsaw has been high for several years [27,28]. Despite the lack of monitoring, wild boar population control commenced in 2008. At that time, eight animals were trapped and removed (i.e., translocated from the city) using four traps. In turn, in 2015, 27 traps located in various parts of the city were used, and 594 animals were trapped (this amounted to 1.15 ind. trapped per 100 ha of the city). In 2014, wild boars started to be shot in Warsaw [29]. Additionally, in 2017, the first case of African Swine Fever (ASF) was recorded in Warsaw (the first ASF case in Poland was recorded a few years earlier in 2014 [30]). Due to the virus itself [31] and the intensive culling of the species, the population was reduced significantly all over the country [25] and in Warsaw, too. After a few years' break, wild boar population control in Warsaw was again undertaken in 2023. According to a decision issued by the President of Warsaw [32], there are between 1500 and 2500 wild boars in the whole city (which gives a density of 3 to 5 ind./100 ha). This assumption supported the decision to remove 500 individuals (through trapping with further euthanasia) over 19 months (June 2024–December 2025). However, the official data from hunting districts covering Warsaw (and neighboring areas) shows a very low population density, around 0.02 to 0.5 ind./100 ha [33].

The reason for our study was to provide science-based data, which may help to develop a data-driven strategy for urban wild boar management in Warsaw. This research was conducted in selected Warsaw areas but also focused on Wawer—the biggest, least urbanized, and most forested district of Warsaw and assumingly among the areas with the most frequent wild boar–human encounters.

We, therefore, aimed to (i) assess the current (2023/2024) density of wild boar in the selected areas of Warsaw, varying in terms of habitat features and location within the city, and compare current data with data for the winter seasons 2020–2022, to show which areas and habitats are used by wild boars and whether the population density changes; (ii) compare winter density assessments obtained by two different methods (snow tracking and camera traps) in two major forest reserves in Warsaw to check whether these density estimates are consistent; and (iii) to conduct complex wild boar density assessment in the most forested district in Warsaw (Wawer district) to deliver an estimation of the absolute wild boar abundance in this part of the city.

## 2. Methods

### 2.1. Study Area

The research was conducted in Warsaw (52°13′47″ N 21°00′42″ E), the capital city of Poland, the second largest (517,100 ha) and the most populous (1,862,000 inhabitants, 3599 inhabitants/100 ha) city of the country [34]. The city is situated at an altitude of around 113 m above sea level, with an annual rainfall of about 500 mm and an average annual temperature of 7.7 °C. The Vistula River flows through Warsaw, dividing the city into two parts. The left bank of the river is characterized by a high degree of anthro-

pogenic transformation, while along the right bank, natural riparian forests, included in the Natura 2000 network and constituting an essential ecological corridor, have been preserved (Figure 1). Forests account for about 15% of the city area and are located mainly on the outskirts. A high proportion of various green areas makes Warsaw easily penetrable for many mammal and bird species. Its green areas are also important refuges for numerous animal species, e.g., [35,36].

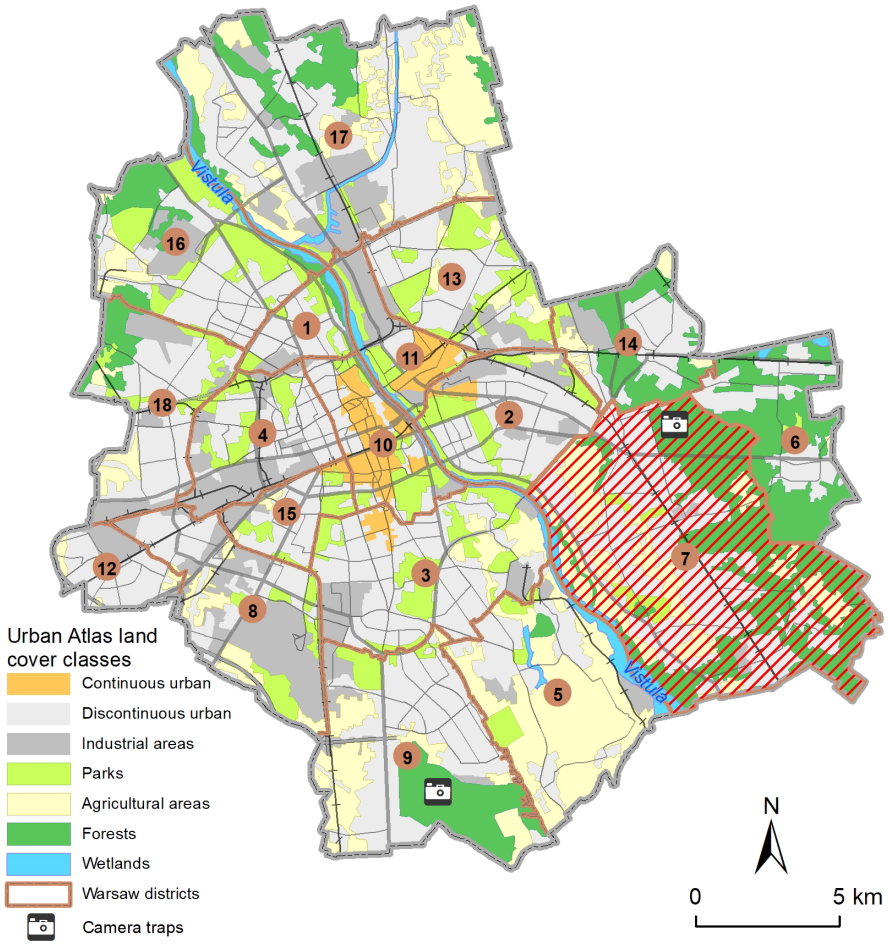


**Figure 1.** Distribution of green areas and other habitats in Warsaw. The numbers refer to city districts: 1—Żoliborz, 2—Praga-Południe, 3—Mokotów, 4—Wola, 5—Wilanów, 6—Wesoła, 7—Wawer, 8—Włochy, 9—Ursynów, 10—Śródmieście, 11—Praga-Północ, 12—Ursus, 13—Targówek, 14—Rembertów, 15—Ochota, 16—Bielany, 17—Białołęka, 18—Bemowo. The research was conducted in city districts no. 2, 3, 7, 9, 10, 14, 15, 16. The dashed area shows Wawer, the city district where complex wild boar density estimation was conducted. Study plots where camera traps for REM density estimation (see Section 2.4) were located are shown.

Warsaw is divided into 18 districts, among which Wawer (Figure 1) is the biggest (7971 ha, 16% of the area of the city) and the most forested. Wawer is the peripheral district, which was included in the capital city in 1951. Officially, it has over 87,000 inhabitants (1095 inhabitants/100 ha). Built-up areas cover almost 2800 ha, arable lands (partially fallow) over 2000 ha, and forests nearly 3000 ha [34,37]. Wawer's forest cover is the largest in Warsaw, surpassing 35%. Forests are located primarily in the eastern part of the district and are dominated by pine stands planted after World War 2. Around 150–200-year-old oaks dominate just a tiny fraction of the forests. The biodiversity hot spots are riparian forests at the Vistula River (also the western part of the city district) and alder swamp forests of the Zakole Wawerskie. A considerable part of the area is under some form of nature protection.

### 2.2. Study Sectors

Fieldwork was performed in 8 out of 18 city districts, 4 inner (Ochota, Śródmieście, Mokotów, and Praga Południe) and 4 outer districts (Wawer, Rembertów, Ursynów, and Bielany), and within 19 sectors, located in different districts (Figure 1). Seven sectors were located in Wawer. Five were located in Bielany, two in Ursynów, and the rest in the other investigated districts (Table 1). The borders of the sectors were major streets, the Vistula River, or compact built-up areas, which made them easily identifiable during the fieldwork. The sectors differed in terms of their area and habitat structure. Ten sectors were forest-dominated; the rest were covered by other habitats (parks, riparian areas, or built-up areas). The forest-dominated sectors differed regarding stands, age, composition, and the area's status. A detailed description of the sectors can be found in Appendix A.

**Table 1.** Description of the sectors in which the fieldwork was conducted. The total transect length on which snow tracking (see Section 2.3) was carried out is given. nd—no snow tracking data.

| Sector No. | City District | Area (ha) | Habitat | Transect Length (m) | |
|---|---|---|---|---|---|
| | | | | 2020–2022 | 2023–2024 |
| 1 | Wawer | 527.1 | forest | 34,330 | 12,480 |
| 2 | | 388.2 | forest | 9820 | 10,400 |
| 3 | | 830 | forest | 4240 | 15,040 |
| 4 | | 1113 | forest | nd | 13,600 |
| 5 | | 1322 | other | nd | 11,200 |
| 6 | | 340.6 | other | 12,960 | 7040 |
| 7 | | 540.4 | forest | 5600 | 13,760 |
| 8 | Rembertów | 155.5 | forest | 14,720 | 4320 |
| 9 | Praga Południe | 184.9 | other | nd | 10,000 |
| 10 | Ursynów | 1108.5 | other | 12,560 | 12,310 |
| 11 | | 89.4 | other | 5770 | 2320 |
| 12 | Mokotów | 96.4 | other | 1400 | 3360 |
| 13 | Śródmieście | 456.6 | other | 10,650 | 10,000 |
| 14 | Ochota | 86.9 | other | 7600 | 1000 |
| 15 | Bielany | 291.8 | forest | 2310 | 4760 |
| 16 | | 129.5 | forest | 1820 | 5320 |
| 17 | | 56.7 | forest | 2240 | 2240 |
| 18 | | 233.5 | forest | 4270 | 3600 |
| 19 | | 57.0 | other | 1400 | 900 |
| Total | | 5404.0 | | 131,690 | 143,650 |

As one of the aims was to estimate wild boar abundance in a sample city district, i.e., Wawer, most of the district (65%) was covered by sectors (Appendix B). In the remaining part of the district, conducting an inventory was impossible. The area of the sectors was assumed to be at least as big as an estimated home range size of urban wild boar (100 ha, [9]).

We used two methods to assess the density of wild boars in Warsaw during winter: (1) snow tracking on transect routes, and (2) camera traps and random encounter model REM.

### 2.3. Snow Tracking on Transect Routes

Wild boar abundance was estimated based on snow tracking in the 2023/2024 winter season. In each sector, snow tracking was conducted in all habitats. In 16 out of the 19 sectors in Warsaw, snow tracking was also conducted in the past (2020–2022), which allowed us to compare wild boar density indices between the two periods (Table 1).

Snow tracking was conducted on sparsely distributed, linear transects of different lengths divided into 100 m sections. Tracking was carried out one to four days after snowfall. The number of wild boars' trails crossing each 100 m of the transect was registered, and then the relative density index was calculated (N tracks/100 m/24 h) [38]. The number of trails registered was divided by the number of days from the last snowfall to adjust the number to 24 h after the snowfall.

The total area of all the districts where snow tracking was performed in the 2023/2024 winter season was 5404 ha, accounting for over 10% of the city. The total transect length was 143.65 km. The total transect length in 2020–2022 was 131.69 km (Table 1).

For all the sectors in Warsaw, the relative density index was calculated and used to compare those two periods. For the Wawer district, to estimate the total abundance of wild boar in a sector, the absolute density was calculated in each sector by using the FMP (Formozov–Malyshev–Pereleshin) formula [39]:

$$D\ (N\ ind./100\ ha) = 1.57 \times (N\ tracks/km/24\ h)/DMD,$$

where D stands for density, 1.57 is a constant value, and DMD indicates the daily movement distance. No data on the DMD of wild boar in Warsaw was available, so we used the values (DMD in winter = 14 km) obtained for another big city in Poland, Cracow [9]. The mean value from seven sectors was adopted for the part of Wawer, which was not covered by snow tracking. Based on this, the absolute abundance of wild boar was calculated for the whole district.

Searching for the relation between the habitat structure of the sectors and the wild boar density index, we calculated the percentage share of forests and agricultural land (according to Urban Atlas) in the seven sectors (sectors no. 1 to 7) in Wawer (Appendix B). For five forest-dominated sectors (no. 1, 8, 10, 16, and 18), detailed data on stand composition and forest habitat was available [33]. Thus, we could check if there was a relation between the percentage share of oaks *Quercus* spp. older than 50 years (and already producing seeds) and share of deciduous forest habitats within a sector and wild boar density index.

### *2.4. Camera Traps and Random Encounter Model (REM)*

In the two forest reserves (Sobieski Forest, sector no 1, and Kabaty Forest, sector no 10, Figure 1), wild boar population density was assessed with the use of camera traps (Reconyx™ Hyperfire™ PC800, PC900 or PC850, Reconyx Inc., Holmen, WI, USA, Browning® Spec Ops Advantage, Dark Ops Apex, Prometheus Group, Birmingham, AL, USA). Eight camera traps were used in sector no. 1, and nine in sector no. 10 (17 camera traps in total). In the Sobieski Forest, they were placed in the reserve, in its part being surrounded by non-protected forest and as far as possible from streets. In the Kabaty Forest, the traps were located in its central part. The distance between the camera traps was 200–400 m. Data were collected from November 2023 to March 2024 to reflect the density of wild boar in winter. The number of trap days was 788 and 622 in Sobieski and Kabaty Forest, respectively. The camera traps were placed in trees at approximately 50 cm height. We recorded each wild boar appearing in the images without distinguishing between individuals. A new observation was considered if a minimum of 15 min elapsed between subsequent photos or a series of photos showing an animal/animals. This rule was abandoned only when an animal in the photo was different in age, sex, body size, or fur pattern (i.e., spotted), indicating clearly it was a different individual than the one previously registered [36]. We used the random encounter model (REM) to calculate wild boar density.

$$D = y/t \quad \pi/(vr(2 + \theta))$$

We used the number of independent photo captures (y) and camera effort (t = trap days). We used wild boar daily range (v = 14 km/day as assessed for winter) after [9]. The detection distance (r = 5.4 m) was adopted after [40]. The detection angle (θ, 0.69, and 0.96, depending on the camera trap type, in radians) was taken from the camera trap manual.

### *2.5. Statistical Analyses*

Differences in the wild boar density index between the sectors were studied using the Kruskal–Wallis test (the data did not follow a normal distribution, Shapiro–Wilk test, $p < 0.05$). A two-sample paired Wilcoxon test was used to compare density indices between the two study periods. Again, the data did not follow normal distribution (Shapiro–Wilk test, $p < 0.05$).

The correlation between the wild boar density and habitat variables was checked using the Pearson correlation analysis.

## 3. Results

### *3.1. Wild Boar Density in Warsaw*

The wild boar density index (n tracks/100 m/24 h) in Warsaw varied from 0 to 3.58 (0 to 4.0 ind./100 ha). A higher wild boar density was recorded in the city's outer rather than the inner districts (Kruskal–Wallis test, H = 4.84, $p = 0.03$) and mainly in Warsaw's east–south and north parts. The wild boar density was higher in the natural areas (i.e., forests, 1.6 tracks/100 m/24 h; 1.8 ind./100 ha) than in the other habitats (H = 8.17, $p = 0.005$, Figure 2).

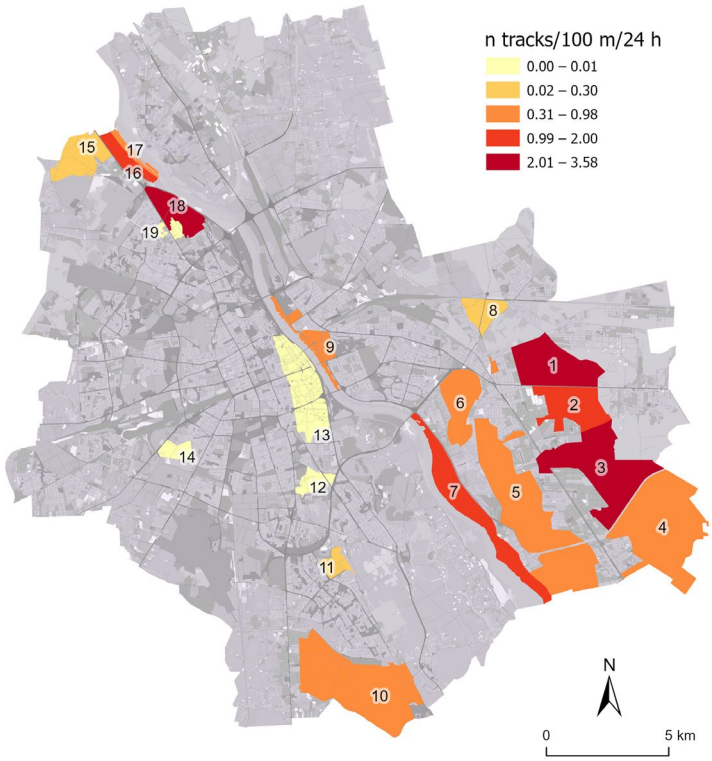


**Figure 2.** Wild boar density index in different areas of Warsaw (i.e., sectors) as assessed by snow tracking on transect routes in winter season 2023/2024. Sector numbers as in Table 1.

The mean wild boar density index in the current period (2023/2024) was higher than in the earlier period (0.47 vs. 1.07 tracks/100 m/24 h) (two-sample paired Wilcoxon test, W = 5, $p = 0.005$). Nevertheless, this increase was evident only in part of the sectors, while in the northern part of Warsaw (sectors no. 16–19), the wild boar abundance remained at a similar level (Figure 3).

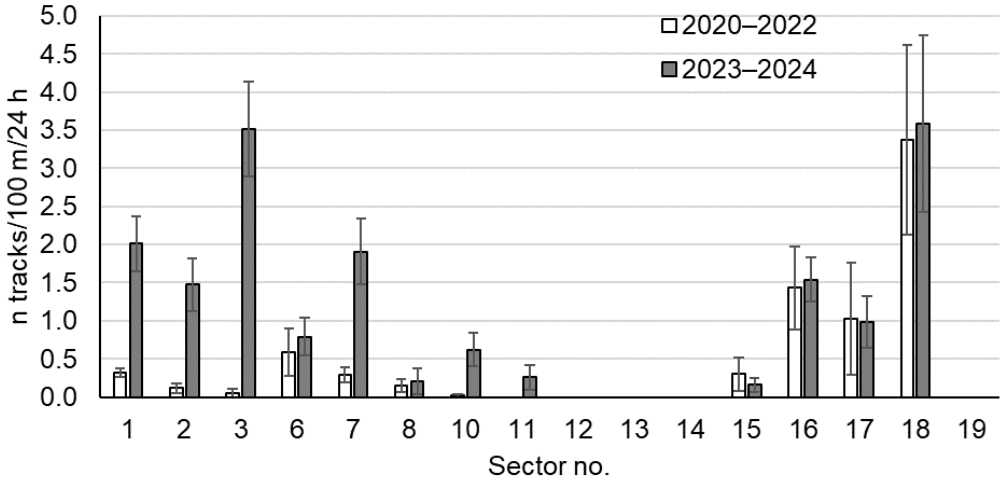


**Figure 3.** Changes in the mean (±SE) wild boar density index in different areas of Warsaw (sector numbers as in Figure 2, Table 1) as assessed by snow tracking on transect routes. Only the sectors where snow tracking was performed in the two study periods are included.

Wild boars seemed more abundant in the forests with a high proportion of oak stands; no relation was seen for the deciduous forest habitats. However, no statistical significance was found (Pearson correlation; oaks r = 0.69, $p = 0.194$; deciduous forest habitats, r = −0.27, $p = 0.657$, Figure 4a,b).

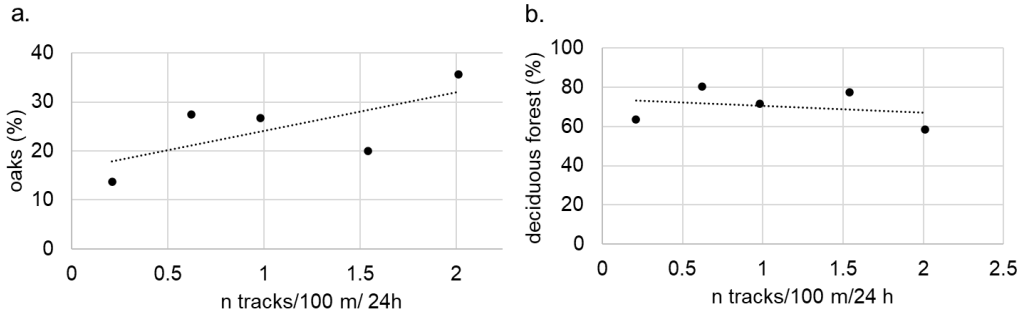


**Figure 4.** Relation between wild boar density index assessed based on snow tracking (winter 2023/2024) and (**a**) percentage share of oaks older than 50 years; (**b**) deciduous forest habitats in a given forest area. Forest-dominated sectors were considered (1, 8, 10, 16, and 18, see Figure 2, Table 1).

### *3.2. Wild Boar Density Estimate with Random Encounter Model (REM)*

In the two forest reserves (Sobieski Forest, sector no. 1, and Kabaty Forest, sector no. 10), we calculated the wild boar density based on a random encounter model (REM). The results obtained by this method were consistent with the snow tracking method. Yet, the values were much higher (Figure 5) than those obtained based on snow tracking (2.3 and 0.7 ind./100 ha for Sobieski and Kabaty Forests, respectively).

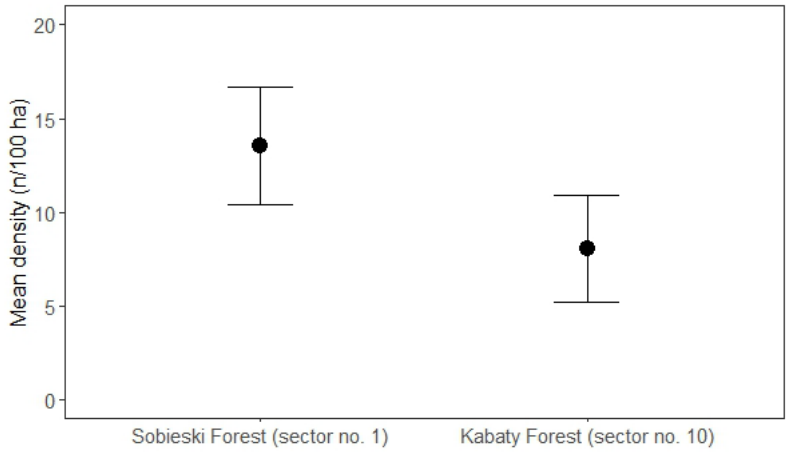


**Figure 5.** Mean (±SE) wild boar density estimated by random encounter model (REM) in two forest reserves in Warsaw (Sobieski Forest, sector no. 1 and Kabaty Forest, sector no. 10) in winter 2023/2024.

### *3.3. Wild Boar Abundance Assessment in One of the City Districts (Wawer)*

In Wawer, the city district in which complex wild boar density assessment was performed, the density index (n tracks/100 m/24 h) ranged from 0.79 in sector no. 6 to 3.44 in sector no. 3. The estimated wild boar density ranged from 0.9 to 3.9 ind./100 ha. The mean estimates for the whole district equaled 1.6 tracks/100 m/24 h and 1.8 ind./100 ha. The total abundance of wild boar in the entire city district was assessed at 103 individuals (Table 2).

**Table 2.** Abundance assessment of wild boar in a city district of Warsaw (Wawer), divided into seven distinct sectors, in which snow tracking on transect routes was performed (2023/2024). To show the total abundance of wild boar in the whole district, the mean density index from sectors 1 to 7 was adopted as the value for the remaining part of the district not covered by snow tracking.

| Sector No. | Area (ha) | Density Index (±SE) (n Tracks/100 m/24 h) | Density (n ind./100 ha) | Abundance (n ind.) |
|---|---|---|---|---|
| 1 | 527.1 | 2.01 (0.32) | 2.3 | 12 |
| 2 | 388.2 | 1.47 (0.31) | 1.6 | 6 |
| 3 | 830.0 | 3.44 (0.56) | 3.9 | 32 |
| 4 | 1113.3 | 0.98 (1.03) | 1.1 | 12 |
| 5 | 1321.7 | 0.9 (0.25) | 1.0 | 13 |
| 6 | 340.6 | 0.79 (0.22) | 0.9 | 3 |
| 7 | 540.4 | 1.87 (0.39) | 2.1 | 11 |
| remaining area | 2909.7 | 1.60 | 1.8 | 13 |
| Total | 7971.0 | | | 103 |

There was a significant difference between the values obtained for the different sectors (Kruskal–Wallis test, H = 22.97, $p = 0.000$). The wild boar density tended to be higher in the sectors with large forest cover and lower when arable lands dominated; however, this was not statistically significant (Pearson correlation, forest cover, r = 0.52, $p = 0.235$ and arable land, r = −0.45, $p = 0.306$, Figure 6a,b).

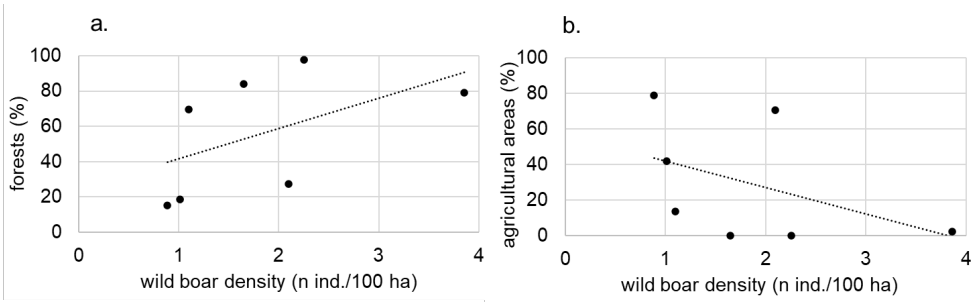


**Figure 6.** Relation between the wild boar density and (**a**) forest cover, and (**b**) share of farmland in a given sector (sectors no. 1 to 7, located in one city district, Wawer) as assessed based on snow tracking on transect routes in winter 2023/2024.

## 4. Discussion

In this study, we showed wild boar density in selected areas of Warsaw. This ungulate species was mainly present in forests. This is in line with the strong preference of wild boar for natural landscapes and areas with high primary productivity [16], as the availability of food resources and protective cover are among the factors that determine wild boar abundance [41]. In our study, the highest densities were obtained for oak-dominated forests, offering plenty of natural food (in the form of acorns) and located in the outer city districts. Also, in Berlin, wild boars mainly inhabited forests [11]. In turn, in another Polish city, Cracow, grasslands and natural open areas were mostly preferred [10]. The wild boars in Warsaw seemed to avoid built-up areas; the same pattern was found in Cracow [10]. They were also less abundant in the areas with arable land domination. Indeed, arable lands were not intensively used for grubbing in Cracow [23]. The two wild boar hot spots (i.e., Sobieski Forest in the south and Bielany Forest in the north of Warsaw) were connected to forests outside the city (including Kampinos National Park) directly or via the Vistula River. Indeed, rivers and their associated riparian forests act as migration corridors for wildlife [12,42,43]. According to this study and other published data, wild boars were absent from the central districts and mostly urbanized areas; this included the biggest Warsaw urban parks, i.e., Mokotów Field [44], Skaryszew Park [45], Szczęśliwice Park, or Royal Łazienki Park (this study). Yet, some accidental presence of wild boars in such green spaces was recorded, with Krasiński Garden, a small, historical urban park, being an example [46]. In general, such centrally located green areas are less appropriate habitats for wild boars, providing fewer hiding places and fewer natural food sources for woody species [8]. Comparing the current data with that collected two years earlier, we see that the wild boar densities increased. Nevertheless, the species was and is still mostly present in areas of high naturalness.

It is hard to claim whether wild boars colonize urban areas or if the city spreads over wild boar habitats [11]. The urbanization process is ongoing, with urban green areas being built up. This makes wildlife search for new, even suboptimal, habitats, leading to more frequent human–wildlife conflicts. Urban forests seem to be crucial as wild boar hot spots. Indeed, wild boar inhabiting urban forests in Berlin formed genetically distinct and geographically coherent clusters. Nevertheless, if these populations exceed carrying capacity, dispersers from urban populations would invade built-up areas [11]. Thus, the regular monitoring of the urban population is necessary.

Wild boar density assessment is difficult [7], and wild boar densities in Poland have recently become very variable due to ASF and increased hunting mortality [31]. For example, in the Roztocze National Park, drive counts showed densities of 16 ind./100 ha, while in the subsequent seasons, this value dropped to 2.2 ind./100 ha and again increased to 12 ind./100 ha [47]. In turn, in the Białowieża Primeval Forest, the wild boar density was estimated at around 7 ind./100 ha based on drive counts. After ASF was recorded, these values dropped to less than 2 ind./100 ha [31]. When another method was applied (i.e., pellet group counts) the assessed density was even much lower (Gryz J., unpbl.). Wild

boar inventory using camera traps in northeast Poland (Iława County) showed a density of 2.5 ind./100 ha of the forest [48]. Inventory in western Poland (Lubusz Voivodeship, areas managed by State Forests) conducted using the same method showed a density of 1.6 ind./100 ha [49]. A complex inventory of wild boars conducted in state forests, using drive counts (autumn 2016), showed a density of around 2 ind./100 ha [50]. However, counting wild boars on a large regional scale is considered unfeasible, and estimations should rather be performed locally and in specific habitats [51]. Besides all this uncertainty over real population abundance, our results on wild boar density in Warsaw do not seem to be high. The mean wild boar density assessed for different areas of the city was from 0 to 4.0 ind./100 ha. In turn, for all the forested areas and for the Wawer district, it was 1.8 ind./100 ha.

Owing to the wild boar population increase and an ongoing urban sprawl, this ungulate has become a new urban species, finding optimal habitats in urban forests that offer abundant food sources. This food supply, combined with higher temperatures in the city (urban heat island phenomenon UHI, [52]), may lead to population increase thanks to reduced juvenile mortality and boosted reproductive success [53]. Additionally, as an omnivorous ungulate, wild boars are often attracted by easily accessible anthropogenic food, including communal waste [7], review in: [8], especially when access to natural resources is limited [54]. They may even enter urban areas looking for pet (i.e., cat) food [12], making them more probable to be recorded by city inhabitants and generating human–wild boar conflicts.

Our results on the wild boar densities need to be taken with caution. Snow tracking in urban areas can be challenging, especially in sectors with a high share of built-up areas or inaccessible plots. The more built-up areas in a sector, the longer stretch at which snow tracking is not possible, e.g., in sector no. 5, snow tracking was possible only along 11 km out of 17 km of our walking distance. In the case of big wild boar packs, it may be difficult to quantify the number of trails crossing the transect. Some sectors were close or adjacent so that the same individuals could travel between the sectors. They were partially separated by streets and built-up areas, but those did not constitute a definite barrier so that the same individuals could be present in different sectors. Moreover, animals from the forests located outside this city district could have entered our study sectors. Besides these shortcomings, our estimations reflect the general distribution of wild boar over the city and in different habitats. We believe the snow tracking method has many pros. It is non-invasive, cost-effective, and can be used over long-term periods and in various habitats, even the most urbanized, where camera trap placement may be difficult. The method may estimate the absolute abundance or deliver the density index, allowing for monitoring population trends and changes in habitat use [38]. On the other hand, it is only applicable with sufficient snow cover; thus, the future use of the method remains questionable. Urban habitats are patchy, with dispersed food or resting sites. This makes wild boars move more to meet their daily requirements [9]. Therefore, the DMD value may reflect local habitat structure, and variation in this value will affect the obtained density value. DMD value should be ideally obtained for a given area or adopted from a study conducted in similar conditions. Thus, the method should be supplemented with other techniques to monitor long-term population trends, such as camera trapping or pellet group counts. The first allows for density assessment (either using the relative index or the absolute density using the REM) but also gives quite precise data on group size, productivity, or activity patterns, parameters that in urban animals may shift as an adjustment to urban conditions [2,36]. In our case, REM gave much higher results than the snow tracking estimations, yet consistent with a general difference between the two forests (i.e., Sobieski and Kabaty Forests). A similar pattern was found in the Białowieża Primeval Forest, where the wild boar density was estimated based on drive counts, and the REM method was compared [31]. REM is suggested to be the most promising methodology for wild boar density assessment [55], yet in urban areas, it may be prone to overestimation [56]. One of the key assumptions of REM is that the pattern of activity of individuals should be random as related to camera

trap placement [57]. This may be violated in heavily penetrated urban forests, where the avoidance of humans may influence wild boar foraging decisions [23]. Moreover, the day range is a crucial REM parameter to obtain unbiased density [57]. This value may differ greatly from that obtained in rural areas and depends on the habitat structure in urban areas [9]. Drive counts are impossible to conduct in heavily penetrated small urban forests. Moreover, they give very variable results, probably related to the highly gregarious behavior of wild boar [55]. A molecular analysis aimed at population assessment [56] and genetic differentiation may help better understand migration patterns between urban and suburban populations [11].

The attitudes of city inhabitants towards wild boar may be very variable [58], with some claiming wild boar eradication/relocation from any urban areas [13] and others being very affectionate about this ungulate species, with attempts to feed wild boars and/or approach not being rare [17,27,28]. Even those who believe wild boar should return to their natural habitats are against wild boar culling [58]. Many people are strictly against wild boar killing, which makes managing wild boar populations in urban areas difficult. In Warsaw, unofficial groups that sabotage the attempts of wild boar population control (e.g., letting wild boar escape from the traps, disrupting wild boar hunts, etc.) are organized. There were also attempts to destroy or steal wild boar traps [29]. Our results did not point to a high wild boar density in Warsaw. Nevertheless, between June 2023 and the time of our study (winter 2023/2024), over 20 wild boars had been culled just in the Wawer district. Unleashed dogs may magnify the conflict between wild boar and humans in urban areas. This domestic carnivore is perceived as a persisting threat by wild boars [16]. Thus, when a dog attacks a wild boar, this ungulate responds, resulting in the dog owner feeling threatened. Indeed, during our study, unleashed dogs were recorded frequently (own observations).

## 5. Conclusions

Wild boar management should start with society's education on wild boar behavior and ecology so that the consequences of certain human actions (like feeding, approaching animals, etc.) are clearly understood. It is clear that a long-term general strategy should be implemented. This should be based on the regular monitoring of wild boar population in the sampled locations, aimed at assessing wild boar population trend, distribution within the city, and population productivity. This should also include hunting districts neighboring the city. At the same time, the protection of forested areas, especially old oak stands, which serve as refuges for wildlife, needs to be safeguarded. Also, regulations (on limited access to people and dogs) must be respected. Wild boar-proof garbage bins are necessary to keep wild boar from built-up areas. Any population regulations should be based on the data delivered by population monitoring, with wild boar trapping and further euthanasia probably being a better solution than wild boar shooting in urban areas.

**Author Contributions:** Conceptualization, J.G. and D.K.-G.; Methodology, J.G., D.K.-G., K.D.J. and M.J.; Formal Analysis, D.K.-G. and K.D.J.; Investigation, J.G., K.D.J., M.J. and D.K.-G.; Data Curation, J.G., D.K.-G. and K.D.J.; Writing—original draft preparation, J.G. and D.K.-G.; Writing—review and editing, K.D.J., M.J. and M.B.; Visualization, D.K.-G., M.B. and K.D.J. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Data is available from the corresponding author upon request.

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

## Appendix A. Description of Study Sectors

Sector no. 1 (527.1 ha) was dominated by forest (98%), part of which (116 ha) was legally protected as a nature reserve (Sobieski Forest). Stands were diverse but dominated

by 70–80-year-old pine and oak stands. Besides, there were natural 150–200-year-old oak stands in the reserve. Most of the forest is managed by the Municipal Forests of Warsaw.

Sector no. 2 (388.2 ha) was also forest-dominated (84%, Barciucha Forest) with a share of built-up (primarily detached or semi-detached houses) areas (13%). Private forest plots are now being built up intensively, including old oak stands, with new roads and other infrastructure being established. The Wawerski Canal runs through the sector.

Sector no. 3 (830 ha) was also mostly covered by forest (79%, Wilanowski Forest), with built-up areas accounting for 14%. Warsaw's southern bypass runs at its southern border. Almost 50% of the forests are or will soon be built up.

Sector no. 4 (1113 ha) was mostly covered by forest (70%), and built-up areas accounted for 13% (primarily detached and semi-detached houses). Its pine stands are young, mostly planted after World War II. Warsaw's southern bypass was its northern border.

Sector no. 5 (1322 ha) was the most urbanized (built-up areas accounted for 27% of the area). Agricultural lands (mostly fallow lands) accounted for 42% of the area; forests accounted for 19% of the area. The whole area is undergoing fast urbanization, i.e., plots are fenced, and new buildings are erected. Along its western border (Miedzeszyński Embankment), there are some wet areas, reed, and willow *Salix* spp. covered.

Sector no. 6 (340.6 ha) encompassed former Vistula floodplains. Forests (15%) were primarily located in its northern part, were alder-dominated, and were protected as a Nature and Landscape Complex (Zakole Wawerskie). The rest of the area is covered by reeds, meadows, and fallow land in various stages of succession (79%). Built-up areas are scarce and account for 6% of the whole area.

Sector no. 7 (540.4 ha) encompassed the Vistula floodplains and was bordered by the river from the west and Miedzeszyński Embankment from the east. The landscape was a mixture of riparian forests (27%) and open areas (meadows and fallow lands, 71%). There are old river beds and swamps in some parts. Built-up areas accounted for less than 2% of the area and were primarily located in the southern and northern parts of the sector. Some recreational areas also existed (like golf courses, boating clubs, and beaches).

Sector no. 8 (155.5 ha, located in Rembertów district) encompassed a woodland cut into two separated areas by a heavy traffic road. Its stands primarily comprise Scots pine (*Pinus sylvestris* L.), oaks, and birch (*Betula pendula* Roth), though most of this site was afforested in the 1950s. Half of the forest (70 ha) is protected as a nature reserve (Kawęczyn reserve) with limited access.

Sector no. 9 (184.9 ha) was located in an inner district (Praga Południe). It encompassed about a 5 km long riparian area (with remnants of willow and poplar forest and some municipal beaches along) restricted by flood bank and the Vistula River. Also, a nearby urban park (Skaryszewski), the National Stadium surrounded by its open areas, and an old river port (now undergoing housing development) were included in this study site. The whole area is intensively used for recreational activities.

Sector no. 10 (1108.5 ha, Ursynów) encompassed the largest compact forest complex in Warsaw (more than 900 ha) and has been protected as a reserve (Kabaty Forest) since 1980. The multi-species tree stands are dominated by Scots pines and oaks, which grow in fertile habitats. Some stands are more than 120 years old. This reserve is contiguous with other Warsaw green areas via the Vistula Scarp. It is surrounded by developed areas, except in the east, where the reserve is adjacent to arable land, an urban park, and a botanical garden. In the protected area, visitors can move only along tourist trails, where walking and biking are allowed. Forest management is highly limited. In the reserve and an adjected urban park, special places are dedicated to leisure activity, barbecue areas, fireplaces, etc. Thus, there are plenty of anthropogenic food remnants that attract wild boars.

Sector no. 11 (89.4 ha, Ursynów) was located on the Warsaw University of Life Sciences campus. Three different habitats can be distinguished: a modern campus with new buildings, an old campus being a historical park, and a nature reserve (Ursynów Scarp). The reserve protects the scarp rising above what was once the proglacial valley that carried meltwaters from the ice sheets. This valley is now considered to be the Vistula

Valley. Protection was provided to a 23 ha area here in 1996, and the reserve includes a multi-species stand of broadleaved woodland. However, the woodland and scrub habitat only accounts for 30%–40% of the protected area. The remainder of the reserve is composed of meadowland and ruderal plant associations. The scarp runs south of the reserve and is connected to woods at the southern edge of Warsaw agglomeration. To the southeast, the reserve borders have more extensive open areas, although these areas are destined for more urban development.

Sector no. 12 (96.4 ha, Mokotów) encompassed two parks (Królikarnia, a historical park adjacent to a historic classicist palace, and Arkadia, now being protected as the Arcadia Nature and Landscape Complex), allotment gardens, sports areas, and XIX fort, all located among highly urbanized parts of the city.

Sector no. 13 (456.6 ha, Śródmieście) covered green areas in a strict city center. These were the historical Royal Łazienki Park, Botanical Garden, Agrykola Park, the surroundings of Sejm and Senate Complex, Marshal Edward Rydz-Śmigły Park, Kazimierzowski Park, and smaller parks and squares located within the built-up areas of the city center and surrounded by busy streets. Some parts of this site are built up by historical and modern buildings. The sector was limited by the Vistula River from the east. Yet, this part of the river bank is highly anthropogenically transformed and deprived of riparian forests and other natural habitats.

Sector no. 14 (86.9 ha, Ochota) included the neighboring Szczęśliwice Park, remnants of Szczęśliwice Fort (part of the 19th century Warsaw Fortress) and adjacent allotment gardens. This municipal park was established in the 1960s in the area, which used to serve as a debris and rubbish dump and clay excavation site (now turned into ponds). The soil is highly degraded, so pioneer species (like poplars) have a significant share among the plants. There is also Szczęśliwice Hill, created initially as a dump for rubble from the destruction of Warsaw during the war, then covered with earth and turned into a slope with a ski lift. The area is a popular recreational site for inhabitants.

Sector no. 15 (291.8 ha, Bielany) was a forest (Młociny Forest) adjacent to sector no. 16 (Młociny Park). This site is directly linked with Kampinos National Park. In the south, it is restricted by one of the biggest Warsaw cemeteries (Northern Communal Cemetery). Tree stands are dominated by Scots pine and oaks with an admixture of birch, black alder (*Alnus glutinosa* (L.) Gaertn), and other deciduous species.

Sector no. 16 (129.5 ha, Bielany) was a forest complex (Młociny Park) with a meadow in the southern part (so-called forest park). Stands are dominated by Scots pine and oaks. The central part of the forest is swampy and dominated by black alder and poplars *Populus* spp. Some pine and oak stands are over 150 years old.

Sector no. 17 (56.7 ha, Bielany) was located along the Vistula River on one side and Młociny Park on the other side. It encompassed a ca. three-kilometer-long riparian habitat mostly covered by willow and poplar forests or bushes. Meadows and oxbow lake complemented the landscape.

Sector no. 18 (233.5 ha, Bielany) was an urban forest (Bielany Forest) surrounding the university campus and historical abbey complex. In its north part, a sports club is located. Most of the forest has been protected as a nature reserve since 1978. Its forest habitats include oak–lime–hornbeam forest, riparian forest, and alder carr. The oldest oak stands are more than 250 years old. Two small watercourses cross the reserve area. On the eastern side, the reserve is partly separated from the Vistula River by a 3-lane expressway (yet it partly runs on a flyover). At the same time, the northernmost limits are connected to the Młociny Park. In contrast, dense urban development is present to the west and south.

Sector no. 19 (57.0 ha, Bielany) encompassed the University of Physical Education in Warsaw campus and a small forest complex (Linde Forest). Stands aged 60–80 are dominated by Scots pine, black locust, birch, and oaks.

## Appendix B. Habitat Composition of Study Sectors (no. 1–7) Located in Wawer City District

**Table A1.** Percentage share of habitats (Urban Atlas Categories) within study sectors (no. 1–7) located in Wawer district.

| Habitat Category | Sector no (% of Area) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Continuous urban fabric | 0.1 | 4.6 | 5.0 | 1.9 | 20.5 | 1.1 | 0.1 |
| Discontinuous urban fabric | 0.0 | 7.3 | 7.2 | 9.7 | 5.7 | 3.6 | 1.0 |
| Discontinuous medium-density urban fabric | | 1.4 | 1.8 | 1.4 | 0.5 | 0.8 | 0.5 |
| Industrial and commercial units | 0.3 | 0.3 | 0.4 | 1.2 | 4.4 | 0.0 | 0.3 |
| Roads | 0.3 | 2.5 | 3.1 | 2.0 | 3.3 | 0.4 | 0.2 |
| Railways | | | 0.3 | 0.0 | | | |
| Construction sites | | | | 0.2 | 0.7 | 0.0 | 0.1 |
| Green urban areas | | | 0.8 | 0.0 | 3.9 | | |
| Agricultural and semi-natural areas | | | 2.2 | 13.6 | 42.1 | 78.8 | 70.5 |
| Forests | 97.8 | 83.9 | 79.1 | 69.5 | 18.6 | 15.3 | 27.4 |
| Water | | | | 0.4 | | | 0.0 |
| Cemetery | 1.6 | | | | 0.2 | | |
| Total area (ha) | 527.0 | 388.2 | 830.0 | 1113.3 | 1321.7 | 340.6 | 540.4 |

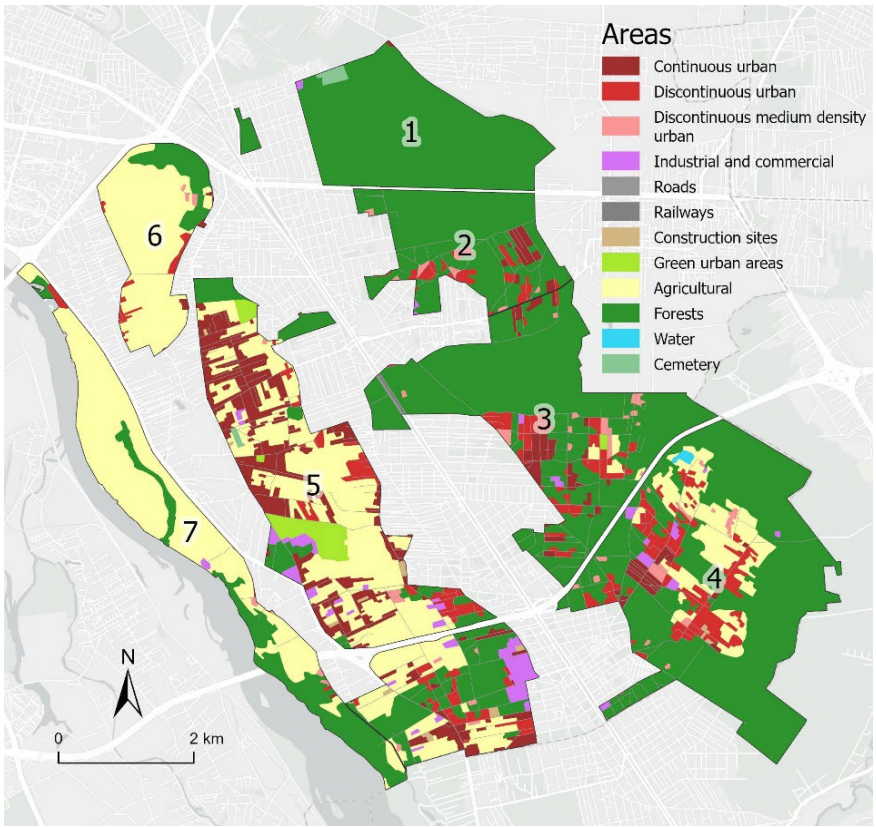


**Figure A1.** Habitat structure of seven sectors (sectors no. 1–7) in which Wawer (city district of Warsaw) was divided to estimate wild boar density.

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