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# Den-Dwelling Carnivores in Central Poland: Long-Term Trends in Abundance and Productivity

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**Abstract:** The monitoring of medium-sized carnivores is essential because of their role in disease transmission and as predators. We focused on red foxes, badgers, raccoon dogs, and domestic dogs, and considered 9441 ha of field–forest mosaic in Central Poland. We compared current (2011–2018) abundance (i.e., number of natal dens recorded annually) and breeding parameters (assessed with the aid of camera traps) with published past data (1980s–1990s). The red fox population increased after rabies vaccinations were introduced and has increased further in the last few years. The population is now stable, which suggests that other factors, possibly mange, limit the population instead. Contrary to historical data, one-fourth of red fox females now breed outside of forests areas, indicating the high plasticity of the species. The number of natal dens of badgers and recruitment rates have also increased. The mean litter sizes of these two species are positively affected by small rodent availability. The raccoon dog, which is an alien and invasive species, used to be recorded sporadically but now breeds regularly (1.8 breeding cases yearly). Nowadays, free-ranging/feral domestic dogs are not controlled by culling, so they have started to breed in the wild (1.6 cases per year), which is a new occurrence.

**Keywords:** red fox; badger; raccoon dog; domestic dog; field and forest mosaic; camera trapping; small rodent abundance



**Citation:** Krauze-Gryz, D.; Gryz, J. Den-Dwelling Carnivores in Central Poland: Long-Term Trends in Abundance and Productivity. *Diversity* **2023**, *15*, 32. https://doi.org/10.3390/d15010032

Academic Editors: Luc Legal and Michael Wink

Received: 2 November 2022
Revised: 16 December 2022
Accepted: 20 December 2022
Published: 27 December 2022



## 1. Introduction

Medium-size denning carnivores—red foxes (*Vulpes vulpes*), badgers (*Meles meles*), raccoon dogs (*Nyctereutes procyonoides*) and free-ranging dogs (*Canis familiaris*)—are frequent objects of ecological studies [1–12]. Nevertheless, most studies in the literature focus only on one species. Domestic dogs and red foxes are the most widespread canids in the world [13–15]; the red fox has been recognized as one of the 100 most invasive species in the world due to its influence on the fauna of Australia [16]. In turn, the raccoon dog is included in the List of Invasive Alien Species of European Union (and Polish) Concern [17]. Monitoring this group of carnivores is essential because they play an important role in disease transmission to other free-living animals, livestock and humans. The most important carnivore zoonosis is rabies [18], which is lethal to humans after the onset of symptoms. *Echinococcus* [19] causes serious health problems in humans, and is mostly fatal if no therapy is initiated. Sarcoptic mange is a very contagious mite infection leading to epizootic skin disease in wild and domestic mammals [20], and badgers are suggested to play a significant role in tuberculosis transmission to cattle [21]. Medium-sized carnivores are also claimed to negatively impact small game [22,23] and endangered bird species [24]. Because of hybridization, free-ranging dogs may pose a threat to wolf populations [25].

Our study was performed in Central Poland and considers field and forest mosaic habitats. Long-term studies of denning carnivores began in this region in 1978 [26]. At present (2011–2018), we have continued the monitoring of carnivorous mammals that commenced in the 1970s. This highly human-affected landscape has undergone considerable socioeconomic transformation, leading to changes in farming practices and farmland structure [27,28]. This has resulted in a drop in the availability of natural prey, i.e., voles [27] and small game [27,29], but also anthropogenic food, i.e., poultry [28] and the carrion of domestic animals [30]. This change is clearly visible in the diet of predatory birds and has affected species abundance [27,28,30]. For example, the Northern goshawk *Accipiter gentilis* could not replace its staple food of anthropogenic origin, so its population abundance dropped by half [28]. This (together with an ability to switch to rodent species other than voles) probably allowed the population growth of the common buzzard *Buteo buteo* [27].

The red fox, utilizes a wide range of habitats—from natural to built-up areas—and consumes a variety of food in different habitats [2,11,31]. The population of the red fox in Poland used to be limited by the zoonosis of rabies. However, thanks to anti-rabies vaccinations, red fox abundance has increased in the last (approximately) twenty years [18,32,33]. The species is no longer heavily hunted (or poached) as a pest (for preying on domestic animals such as poultry), and its fur is not valued [2,11]. As a consequence, overpopulation may lead to emerging and rapidly spreading epizooties (e.g., sarcoptic mange), in turn limiting the number of foxes [34,35]. Indeed, approximately 30% of the red foxes recorded in our study area were reported to have mange symptoms several years ago [36]. We expect that this might have hindered further population increase. Another canid, the domestic dog, is expected to grow in numbers, as stray/feral dogs are no longer controlled [37]. Indeed, free-ranging dogs have recently been shown to be widespread and abundant across the whole of Poland [38]. Free-ranging dogs can act as predators, but also compete with and transmit diseases to wild carnivores [39]. We have shown that dogs in rural areas of central Poland influence space utilization by the red fox [40]. They have been found to kill red foxes, but also raccoon dogs, badgers and polecats (*Mustela putorius*) [3,41,42]. The population of the European badger increased in the 1980s. Although the European badger is not a popular game species in Poland, hunting is one of the main causes of its mortality (often more important than predation). An increase (almost 17-fold) in the harvest rate of this species in Poland in the last four decades [43] might have affected its abundance. At the same time, the population could be affected by numerous free-ranging dogs, but also by mange (also carried by red foxes) [20]. The raccoon dog is widespread in Poland; however, reports of this species from our study area are scarce [42]. Due to its status as an IAS, its abundance must be monitored.

To show changes in the community of medium-sized den-dwelling carnivores, we compared data collected during the current study period (2011–2018) with comparable data from previous decades [3,18] and showed long-term trends in species composition, abundance, and the breeding performance of these target species.

## 2. Methods

### *2.1. Study Area*

The study was conducted in Central Poland, within hunting units no 99 and 122 of the Experimental Forest Station of Warsaw University of Life Sciences, in the vicinity of the village of Rogów (51.8183, 19.88715). This study area covered 9441 ha of field and forest mosaic habitat (Figure 1). The forest accounts for 1599 ha (approx. 17% of the area) and is mostly managed by the Warsaw University of Life Science (WULS) as an experimental research area. Forestry and wildlife management are conducted by WULS. The rural area represents a typical field—a forest mosaic: open areas dominate here, a few hundred hectares woods are surrounded by a mosaic of patches of different crops, pastures, fallow land, and groups of trees. Villages (consisting of rows of settlements along roads) and single farms are evenly distributed in the study area no more than a few kilometers from each other.

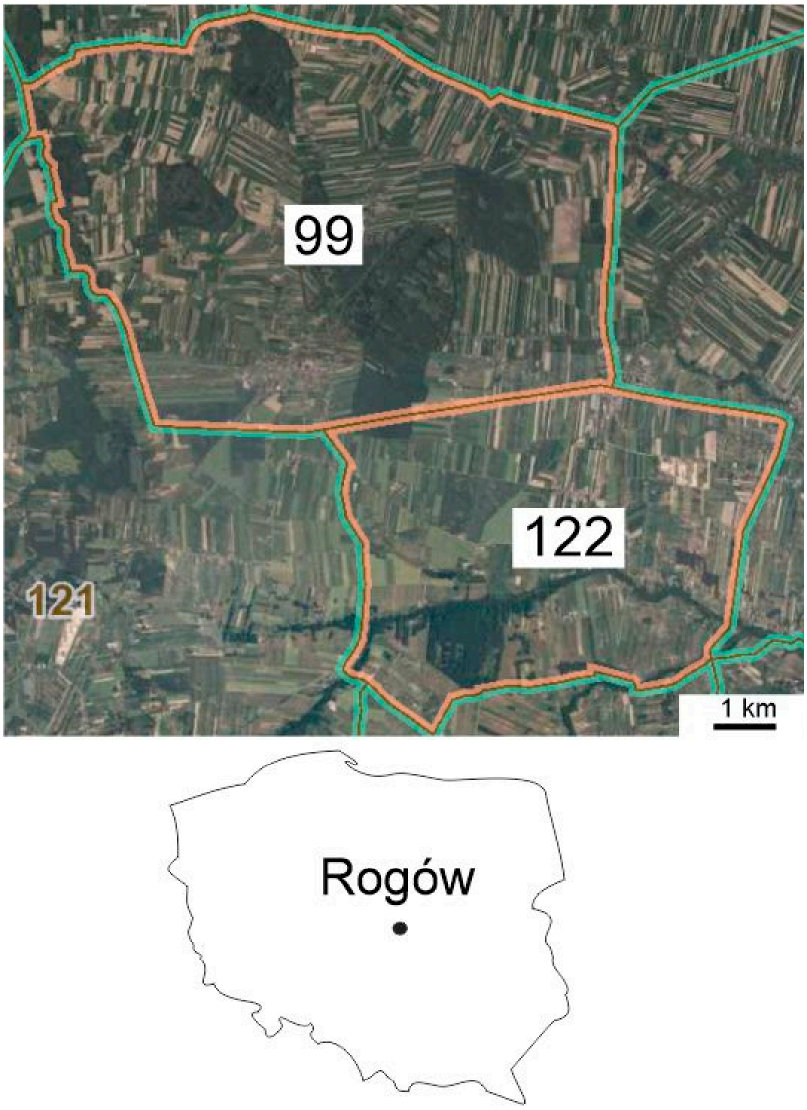


**Figure 1.** The study area located in Central Poland (black dot). The study was conducted in the areas of the hunting units no 99 and 122. Their borders are marked in orange. Source of the maps: [44].

The duration of the growing season was approximately 210 days. The total precipitation was as much as 600 mm per year, and the mean ambient temperature ranged from −4 °C in January to +18 °C in July. There were no large carnivore residents in the study area [42].

## 2.2. Field Methods

### 2.2.1. Estimation of the Number of Natal Dens and Breeding Performance

Natal dens were searched for between 2011 and 2018. In the final year we did not manage to collect precise data on the number of cubs, so breeding performance was estimated for 2011–2017. At first, we checked all sites known from previous studies [3,18,45,46]. We also interviewed local hunters, foresters, farmers and scientists. Nevertheless, most shelters were found during regular fieldwork. Each spring (March–April), all forest complexes, mid-field woodlots, parks and cemeteries were checked to locate all dens present in the study area. Additionally, the forest area was searched thoroughly during the driving census conducted each year and during snow tracking (see below). Moreover, we traversed fields and orchards by cycle or by car searching for dens, visited abandoned buildings, and inspected straw bale aggregations and other areas which could be potentially used as denning sites, applying direct control or binocular observation. All potential reproductive sites found were recorded on a GPS receiver (Garmin 62sc). The preliminary identification of natal dens/setts was based on the presence of animal tracks/prey remains. Next, to check if the shelters were inhabited, we monitored them from early March to mid-July with 28 Reconyx camera traps (Reconyx HyperFire: PC90, PC800, PC850, PC900, RECONYX, Inc., Holmen, WI, USA). We determined the species and the numbers of cubs. Sometimes, if the status of the badger sett was not obvious (i.e., we did not record juveniles but the sett seemed to be occupied), we monitored the site for the whole year. In cases where badger setts were large and extensive (i.e., with 5–8 different entrances) we used two or three cameras on one site. On the basis of the photos from the camera traps, we decided if the den/sett was used as a breeding site and counted the number of juveniles (estimated as the highest number of juveniles observed at the same time). Apart from camera trapping, we also conducted direct observations of reproduction sites using thermovision cameras (Bullard TacSight) or IR noctovision binoculars (Yukon NVB Pro 2.5 × 42). If no cubs were recorded in a den with clear signs of animal presence, neighboring dens/setts were also checked in case juveniles were carried by female [18]. If the number of cubs was clearly estimated, we moved the camera traps to new localities to observe as many dens as possible. Each den was observed with camera traps for at least a month.

To compare the number of breeding cases of the four carnivores, we reported only those dens/setts in which juveniles were recorded. Moreover, in the case of badgers, to compare density and the number of setts with data from past years, we applied the methodology adopted by Goszczyński and Skoczyńska [3]. In essence, an occupied sett was defined as a site where animals reproduced or spent winter. Nevertheless, in some cases we also included sites where at least one animal was present during spring/summer, but we were not sure about breeding or wintering [3]. Such a sett was taken under consideration if it was located more than 1.5 km from other inhabited setts and had at least two entrances. These setts were included in the total number of setts for the sake of comparison with data from previous periods. Solitary badgers recorded at these setts were included in the total number of badgers (adults and cubs pooled together) to calculate the density of badgers per forest area in late spring. The badgers could not be recognized individually, so the number of individuals might have been biased. In case of doubt, we recorded the highest number of badgers observed at a den at the same time. Recruitment was calculated as the number of juveniles observed per adult badger [3]. A proper assessment of the number of adult dogs in one pack was sometimes particularly difficult because stray (feral) dogs may be joined temporarily by free-roaming owned dogs. Thus, we reported the highest number of dogs recorded at one den.

#### 2.2.2. Snow Tracking

In order to compare past and present red fox densities, a relative index of abundance was assessed on the basis of snow tracking on transects. The fieldwork was performed in the winter seasons from 2011 to 2018. Snow tracking was conducted on linear transects of different lengths that were sparsely distributed in the open areas and in the forests (287 km in total). Tracks were identified on the basis of shape, size and the placement of toe pads [47]. To make the collected data comparable, we conducted snow tracking in the same areas each year. We counted the number of red fox trails crossing the transect. Next, the index of species density was calculated (N tracks/1 km/24 hrs). We carried out tracking 1–3 days after a snowfall so we adjusted the number of tracks registered for 24 h of snow cover persistence.

#### 2.2.3. Drive Counts

In the forest, red fox density was assessed with the aid of drive counts [18], performed by students of biology (WULS), in early March between 2011 and 2018 (data from the Department of Forest Zoology and Wildlife Management, WULS). The animals were counted in selected plots (i.e., one plot consisted of one or two forest compartments). The censused area accounted for around 30% of the whole forest complex (i.e., usually 3–4 plots, each 12–24 ha were censused). The censused area was considered in terms of stand age, species composition, and the distance from the forest edge. Each rectangle plot was surrounded by observers standing 50–100 m apart (to maintain visual contact), around one hundred students were simultaneously involved. The observers along three sides of the plot stayed in place, while those along the fourth side moved inward and walked through the entire area, rousing the animals from the plot. All observers noted the animals passing through the line of observers and the closed area that was being censused. Each person counted only the animals passing by on their left side to avoid duplications. On the basis of the number of observed red foxes within the plots and the total area of the plots, the density of animals per 100 ha was calculated.

#### 2.2.4. Live-Trapping of Small Rodents

As the availability of small rodents in spring is crucial for the breeding success of the red fox [2], and may be also important for the badger [48], we conducted parallel counts of small rodents (live-trapping) in the field and in the forest in early May from 2011 to 2017 [49]. Each trapping area was a 90 m $\times$ 50 m rectangular shape (0.45 ha), 50 traps were used, separated by 10-metre distances and arranged in a grid pattern. Traps were set in the afternoon, baited with oats, and left open for at least 12 h. Next, we checked traps twice a day, over three days, to generate a relative index of rodent population density (number of individuals per 100 trap days) for the consecutive years. Rodents were marked to avoid double counting, and the species was identified.

### *2.3. Long-Term Trends*

To show changes in red fox and badger densities, we referred to published data [3,18]. Den search, snow tracking and driving census during the current and the past periods were completed in the same way to make collected data comparable [3,18]. In the case of the red fox, we examined Goszczyński's [18] data for the two periods of 1980–1995 (before vaccination against rabies started in our study area) and 1996–2000 (after vaccination started) and compared them with our data (i.e., the number of breeding cases per year, the number of cubs/litter, population density assessed with the aid of snow tracking and driving census). In the case of badgers, we were not able to stick to the same periods, nor we could adopt the same periods for all comparisons. This was due to the fact that in the study by Goszczyński and Skoczyńska [3], the areas checked for badger setts varied between years and no raw data were available. Thus, to compare the absolute number of badger setts present in the area, we chose only the years in which searches were completed in exactly the same area as in our study. The density of juveniles and mean annual recruitment could be compared for wider periods. In general, the time frames refer to the 1980s and 1990s.

### *2.4. Statistical Analysis*

The Mann–Kendall trend test was used to assess whether the time series presenting the number of breeding cases of the red fox and the badger between 2011 and 2018 had a monotonic upward or downward trend. The mean number of cases of red fox and badger breeding in the 2011–2017 study period was compared with the Mann–Whitney test. To show differences between the number of breeding cases of the four carnivores we used the Mann–Whitney pairwise test. Pearson correlation was used to assess the correlation between the breeding parameters (n of juveniles per one breeding case) of the red fox and the badger and rodent availability. To compare the density of badgers (adult and juveniles orjuveniles only), and recruitment rate in the three periods, we used the Kruskal–Wallis test, with the Mann–Whitney pairwise test to show differences between certain years. The analyses were completed with Past 4.05 [50] software.

## 3. Results

### *3.1. The Number of Breeding Cases of the Four Carnivores*

The red fox was the most numerous species. The number of reproductive sites found annually varied from 17 (in 2011 and 2014) to 23 (in 2013). Altogether, we recorded

153 breeding cases of the red fox in 67 different sites, with 2.3 breeding cases per site. On average, 19.1 (SD = 1.96) breeding cases were recorded each year and there was no statistically significant trend (2011–2018) regarding the number of reproductive dens of the red fox (Mann–Kendall test, S = 5, $p$ = 0.274, Figure 2). Of all the recorded dens, 16 (23.9%) were outside the forest areas. Cubs from 63 litters were born in ground dens. Foxes bred in shelters in straw bale aggregation in two cases, once in an abandoned (collapsed) cellar, and once in an old, non-functioning drainage pipe. In one case, we detected the simultaneous successful reproduction of foxes and badgers in one large complex of setts.

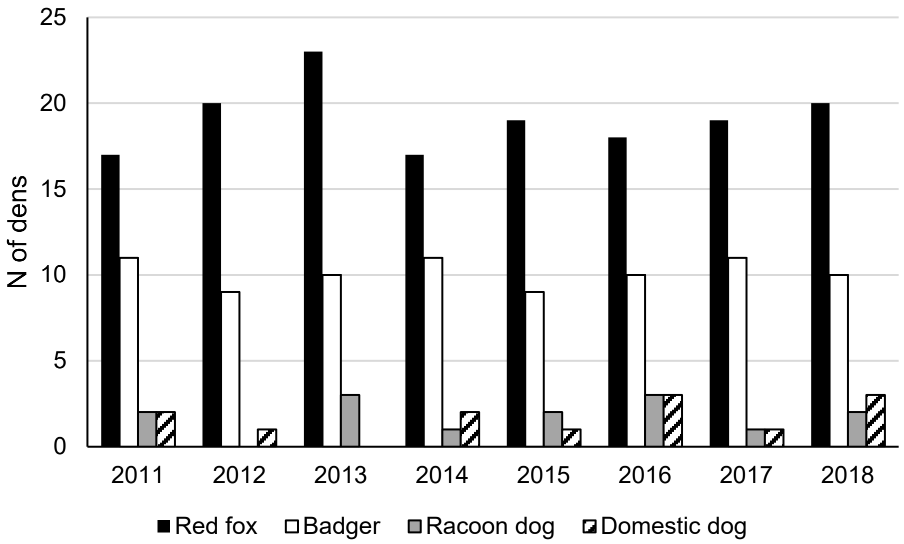


**Figure 2.** Numbers of dens with cubs of the three medium-sized carnivores and feral/stray dogs recorded annually in the study area (field and forest mosaic, Central Poland) in the eight-year study period.

The mean number of natal dens of badgers recorded per year was lower than that of the red fox (10.1, SD = 0.83) (Mann–Whitney test, Z = 3.34, $p < 0.001$), and varied from 9 (in 2012 and 2015) to 11 setts (in 2011, 2014 and 2017, Figure 2). Again, no significant trend in the number of breeding dens recorded annually was recorded (Mann–Kendall test, S = 9, $p > 0.05$). Altogether, badgers bred 81 times in 17 different places (4.7 breeding cases per one site). Most of the breeding sites were located in forests, one was in an orchard, and one was in an old, abandoned park. The oldest still-occupied sett in our study area had been known before 1914.

The other two species of carnivores were much less numerous than the red fox and the badger (Mann–Whitney pairwise test, $p < 0.05$ for comparisons between red fox/badger and raccoon dog/domestic dog, $p > 0.05$ for comparisons between raccoon dog and domestic dog, Table S1). The number of natal dens of the raccoon dog recorded annually was 1.8, on average (SD = 1.04), and varied from 0 (in 2012) to 3. We identified 14 litters across 7 different sites. Raccoon dogs bred in a former fox den in three cases, and in one case in a former badger sett. One reproduction site was located in a burrow created by beavers at a pond edge, one in the base of a fallen, rotten tree trunk, and one in a pile of branches, sawdust and leaves. Two of the recorded reproduction sites were located outside of forests. The number of breeding cases of domestic dogs was on average 1.6 (SD = 1.06) and varied from 0 to 3 (Figure 2). We recorded 13 breeding cases in 7 different sites: one in a self-dug burrow, one in a fox's den, one in a badger's sett, two in fields of grain, one in an abandoned building, and one under a fallen tree. Four of the breeding sites were located in forests.

*3.2. Breeding Parameters of the Four Carnivores*

The number of the red fox cubs in a litter ranged from one to six. The mean litter size varied between years (Kruskal–Wallis test, H = 35.9, $p < 0.001$). The lowest average litter size (2.5 cubs, SD = 0.62) was recorded in 2011 and the highest (4.1, SD = 0.63) in 2013 (Table 1). The average number of cubs in one litter was 3.5 (SD = 0.86, N = 130, 2011–2017). We never recorded more than two adult individuals at the same time in the vicinity of a certain den. The number of natal dens (Pearson correlation, r = 0.9; $p < 0.005$) and the numbers of cubs (r = 0.77; $p < 0.005$) were positively affected by small rodent abundance recorded in spring of the same year (2011–2017).

**Table 1.** Mean (±SD) number of red fox and badger cubs per litter and recruitment of badgers (N juveniles/N adults) recorded annually in the study area (field and forest mosaic, Central Poland) in the seven-year study period.

| Year | Red Fox | Badger | |
|---|---|---|---|
| | Litter Size | Litter Size | Recruitment |
| 2011 | 2.5 (0.62) | 2.5 (0.69) | 1.0 |
| 2012 | 3.2 (0.85) | 2.6 (0.88) | 0.9 |
| 2013 | 4.1 (0.63) | 3.3 (0.67) | 1.3 |
| 2014 | 3.5 (0.51) | 2.6 (0.67) | 1.2 |
| 2015 | 3.5 (0.62) | 2.6 (0.73) | 1.0 |
| 2016 | 3.5 (0.83) | 2.8 (0.63) | 1.1 |
| 2017 | 3.4 (0.91) | 2.5 (0.93) | 1.1 |
| Average | 3.5 (0.86) | 2.7 (0.77) | 1.1 (0.14) |

The number of the badger cubs varied between one and four, with 2.7 on average (SD = 0.77, N = 71, 2011–2017). The mean litter size was less variable than in the case of the red fox: the lowest mean number of cubs was 2.5 (in 2011, 2017), the highest was 3.3 (in 2013). There was no statistical difference between years (Kruskal–Wallis test, H = 6.78, $p > 0.05$) (Table 1). Nevertheless, the mean number of cubs in a litter (but not the number of litters recorded, $p > 0.05$) was positively corelated with the abundance of small rodents in spring of the same year (r = 0.91, $p < 0.005$). The mean number of adults in a sett was 2.1 (SD = 0.44) (including setts without detected cubs and solitary individuals).

The number of observed cubs of the raccoon dog varied from 4 to 8, with an average of 6.5 (SD = 1.31). The number of recorded cubs of the domestic dog was from 1 to 6, with an average of 3.85 (SD = 1.46). Reproduction sites of domestic dogs were inhabited by various numbers of adult individuals. In most cases there was a female with cubs, but we also detected a group of nine dogs including two reproductive females.

### *3.3. Long-Term Changes in the Density and Breeding Parameters of the Red Fox and the Badger*

The number of natal dens of the red fox recorded annually increased compared with past data. Nevertheless, this increase seemed to be lower than the difference between before and after rabies vaccination started (Table 2). Similarly, an increase in density assessed with the aid of snow tracking was recorded (Table 3). Nevertheless, the red fox density assessed with the aid of the drive counts was higher than that recorded in the first period (before rabies vaccination), but lower than that recorded in the second period (after rabies vaccination) (Table 3).

**Table 2.** The number of natal dens recorded annually and breeding parameters of the red fox in the study area (field and forest mosaic, Central Poland) in the three periods: 1980–1995, 1996–2005 [18], 2011–2018 (this study). b—before rabies vaccination; a—after rabies vaccination; * litter size assessment was performed from 2011 to 2017.

| Study Period | Mean (±SD) Number of | | Natal Dens |
|---|---|---|---|
| | Natal Dens | Cubs per Litter | Outside Forests (%) |
| 1980–1995 $^{b}$ | 9.33 (1.70) | 3.79 (1.07) | 2.7 |
| 1996–2005 $^{a}$ | 15.0 (3.55) | 3.39 (0.99) | 13.3 |
| 2011–2018 | 19.1 (1.96) | 3.5 (0.86) * | 23.9 |

**Table 3.** Mean (±SD) density of snow tracks of the red fox (N tracks/1 km/24 h) and mean (±SD) spring density of the red fox based on the drive counts assessment in the study area (field and forest mosaic, Central Poland) in the three periods: 1980–1995, 1996–2005 [18], 2011–2018 (this study). b—before rabies vaccination; a—after rabies vaccination. Snow tracking was performed both in the forest and in open fields. Driving census was completed only in forests.

| Study Period | Snow Tracking | | Drive Counts | |
|---|---|---|---|---|
| | Length of Tracking (km) | N Track/km/24 h | N of Censuses | N/km$^2$ |
| 1980–1995 [b] | 1245 | 5.9 (1.78) | 12 | 1.22 (1.08) |
| 1996–2005 [a] | 383 | 11.0 (2.82) | 9 | 2.58 (1.28) |
| 2011–2018 | 287 | 16.0 (2.08) | 8 | 1.88 (1.12) |

The number of setts inhabited by badgers rose over time. During our study, there were 12 setts every year (including setts inhabited by solitary badgers), compared with 7–10 setts recorded in the 1980s–1990s [3] (Table 4). Additionally, the density of badgers calculated for the forest area (based on the number of all individuals or just juveniles observed at a sett) was higher in the later period than in the previous ones (Kruskal–Wallis test, density of adults and juveniles: H = 13.47, df = 2, $p < 0.005$; density of juveniles: H = 12.00, df = 2, $p < 0.005$; recruitment: H = 6.70, df = 2, $p < 0.05$) (Table 4 and Tables S2–S4).

**Table 4.** Number of inhabited badger setts (including groups without cubs and solitary badgers), estimated (mean(±SE)) density of badgers (adult and juveniles) in May/June calculated per forest area, and recruitment (N juveniles per N of adults) in the field and forest mosaic (Central Poland) in the three periods: data for the first two periods from Goszczyński and Skoczyńska [3], and 2011–2018 (this study). To compare the absolute number of setts between periods we used only those years which encompassed the same study area. For other comparisons (density, recruitment), we used all available past data.

| Study Period | N Setts | Study Period | N Ind./km$^2$ | | Recruitment |
|---|---|---|---|---|---|
| | | | All Individuals | Juveniles | |
| 1984–1986 | 7–8 | 1979–1989 | 1.6 (0.20) | 0.6 (0.17) | 0.7 (0.38) |
| 1995 | 10 | 1990–1995 | 2.2 (0.37) | 0.8 (0.43) | 0.7 (0.37) |
| 2011–2018 | 12 | 2011–2017 | 3.3 (0.24) | 1.7 (0.22) | 1.1 (0.14) |

## 4. Discussion

The density of red foxes has increased across the whole of Poland in recent decades [11,32]. Between 1980 and 2005, the population increased significantly following rabies vaccination, which in our area commenced in 1993. Simultaneously, the number of cubs in a litter decreased slightly [18]. We showed a further increase in red fox abundance, i.e., the number of dens with cubs recorded each year and the density index based on snow tracking. At the same time, we recorded no increase in the drive counts population density assessment (or even a decrease compared with 1996–2005) [18]. This can be explained by the fact that the use of open areas by foxes has increased in recent years. In the past, most of red fox dens were located in the forest and open areas were used for foraging [26]. As red foxes are very flexible in their use of environmental resources [2,26,51], and due to their increased population, they started to breed closer to people, and outside forests. Indeed, we found almost one-fourth of dens outside the forest, which explains why the driving census may not be a good way to assess the general density of the species in an area with a high share of open spaces. We have also shown previously that the red fox adapts to changes in food availability. Consequently, domestic birds (poultry) and small game are now much less frequent in its diet, and foxes use various human refuse [29]. We recorded no year-to-year increase in the number of foxes breeding in the study area during this study, which suggests that the population abundance became more stable. Similarly, in the UK, after a sharp increase in red fox numbers, the population stopped rising and started to decline [52]. This suggests that the population is now limited. This may be due to sarcoptic mange. Unfortunately, we have no detailed data on the number of foxes affected by mange. Nevertheless, this disease was already present in the population several years ago [36]. Sarcoptic mange is known to be able to effectively limit red fox populations [35]. However, there are also reports that it does not need to have a severe impact on the population (review in [20]), and the species could adapt to the presence of the pathogen [53]. Regardless of the future impact of mange on the red fox population, its prevalence will lead to inter-species transmission, as the species is reported to be the main reservoir and carrier of sarcoptic mange [20]. Consequently, other carnivores may be affected by the zoonosis. Hunting pressure has not seemed to affect population in the long term. The hunting bag of red foxes was very low in the 1980s and mid-1990s (on average, 6 individuals were shot per year in the two hunting districts under study). This increased in the next period (to 45 ind. on average, but was very variable, from 9 to 72 ind. per year) as a response to the growing density of the species [18]. The maximum values of hunting deaths were reached in the years with fox bounties. Nowadays, fox hunts are not supported, nor are they profitable for hunters, as fox fur has no real value today. Nevertheless, hunting bag still results in the death of around 40 individuals per year (Figure 3).

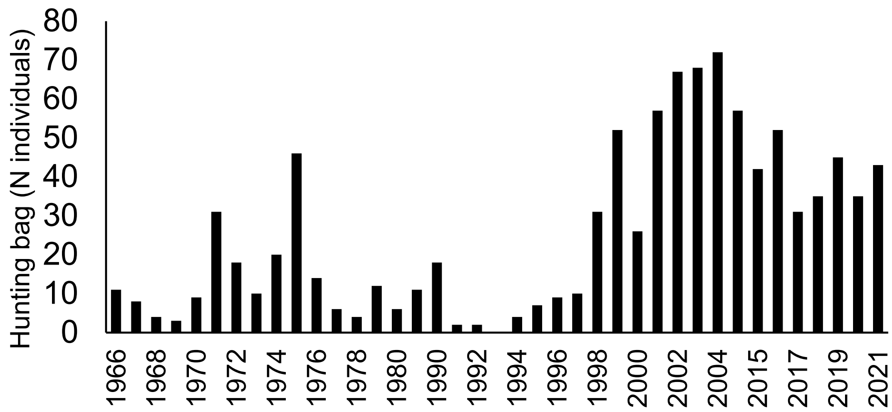


**Figure 3.** Hunting bag of the red fox in the study area (data from the Experimental Forest Station in Rogów, Forest Data Bank—Hunting Reports).

It is not clear what factors have caused the badger population to grow in past decades. However, an increase in the badger population was also recorded in the UK [52]. Goszczyński and Skoczyńska [3] suggested that an increase in the area of orchards (and thus in food availability) was beneficial for badgers in our study area in the 1990s. Fruits are an important part of badger diet in Central Poland [48]. However, after 1995, we did not observe an increase in the share of orchards in the landscape. Badger population may be positively affected by climate warming [54], which may positively influence cub survival [55]. Indeed, winter and early spring temperatures showed an upward trend (1924–2015) in our study area [56]. Earthworms are an essential part of the badger food base [48]. Nevertheless, hydrological droughts observed in the whole of Poland and in our study area in recent decades [57] might limit this food source [58]. The trend observed in our study is consistent with other data in many other locations in Europe [54,59,60]. The hunting of badgers is claimed to be one of the factors that may limit the population [43]. Indeed, the hunting bag is now negligible (i.e., only one badger was harvested in the last six years of our study period) [61]. Additionally, cases of poaching (which used to be scarce) are not recorded anymore, as badger does not make a valuable trophy. Nevertheless, hunting was never frequent in the study area of Rogów. Between 1979 and 1995 just ten badgers were shot by hunters [3]. Badgers and red foxes coexist successfully [62], and cohabiting setts with red foxes did not seem to affect litter size negatively [10], so an increase in the number of red foxes should not affect badger population directly.

The raccoon dog is an alien and invasive species in Poland [63]. It was recorded in Poland in 1955 for the first time [64], and short after it began fast expansion across the country [65]. At present, the raccoon dog is found across the whole country; however, it is still not very widespread in Central Poland [66]. At the same time, in some areas of North East Poland (where its invasion has started) the raccoon dog is the most abundant denning carnivore [4]. It was first noted in our study area in 1978, when a skull was found at the fox den in the Popień forest complex. It has been sporadically hunted since the beginning of the 20th century [42], and only four individuals were ever harvested in our study area [67]. The first den with cubs of the species was found in 2010 in a dike of an abandoned fishpond [68]. Since 2011, when our study started, cases of breeding were observed almost every year. This suggests that, most probably, we recorded an initial stage of raccoon dog population development in the study area. Thus far, no more than three litters have been recorded per year, and no clear increase in the population has been seen. Nevertheless, we may expect that after this initial stage of colonization, the population will start to rise. We did not record the occupation of inhabited badger setts by raccoon dogs (yet, old badger and red fox dens were used by raccoon dogs). Nevertheless, the co-habitation of setts (especially during strong winter) is important for raccoon dogs [69]. We may thus speculate that an increase in the number of available setts, which we observed during our study, will be facilitative for the raccoon dog.

The legal status of free-ranging dogs in Poland has changed over the years. First (from 1959 and till the mid-1990s) hunters were supposed to eliminate game pest dogs from the hunting ground. From the late 1990s and until 2011, dogs that went feral could be killed under specific circumstances (i.e., being more than 200 m from a building, or posing a threat to wildlife). Currently, it is only acceptable to shoot dogs if they pose a threat to people or animals [37]. Nevertheless, as dog shooting is opposed by most of society, this is very infrequent. Hunting data from the past show that the problem of stray/feral dogs was serious, i.e., between 2003 and 2006, 34 to 66 dogs were shot annually in our study area. This was close to the harvest rate of red foxes at that time [67]. In the 20th century, when hunters were obliged (or allowed) to shoot free-ranging dogs, their numbers were clearly limited. Thus, cases of reproduction in the wild were noted only sporadically, i.e., between 2003 and 2010, they were recorded only three times [37]. Since the law has changed, and with an increasing resistance from the public, hunters shoot dogs only sporadically. As a result, we observed on average almost two cases of dogs breeding in the wild annually. With no real control of the domestic dog population, we may expect a further increase in the number of such cases. Dogs in the study area often allowed to roam uncontrolled at night. There were numerous predators in our study area. The spot-light count on transects data showed that dog density was 2.2 ind./km$^2$, which was lower than that of the domestic cat *Felis catus*, but higher than that of the red fox [37]. Similarly, when we recorded the number of visits to tracking stations, dogs were found to be more numerous than red foxes [40]. The status of these free-ranging animals is difficult to assess. Most of them probably have owners but stay uncontrolled, especially at night [37,40]. Indeed, the activity of dogs is concentrated near buildings [40]. Some of them may be homeless, as dogs are abandoned (especially close to or during summer holidays) regularly [70]. Regardless of their origin, dogs may go feral, start reproducing in the wild, or hunt wildlife [37,42]. They could also have a strong negative effect on other predators, being a dominant species [40]. Indeed, during our study (on the basis of camera trapping data) we detected numerous cases when dogs tried to enter occupied fox dens in the breeding season. In one case, dogs probably killed all fox cubs. We also noted 11 cases when dogs entered an occupied badger sett. In one case, an adult badger was killed and partially eaten by dogs 300 m from a set [70].

## 5. Conclusions

The abundance of the four carnivorous species increased during our study compared with past data. The factors that lay behind this population increase seem to be different for each species. Nevertheless, the harvest rate did not reflect changes in population density, nor was this the factor driving the population changes. The red fox was further able to increase in numbers (after it initially became more abundant when rabies zoonosis was eliminated) thanks to its plasticity and ability to breed in non-optimal habitats (i.e., open fields). The increase in the population of badgers was probably thanks to the high recruitment rate. In the case of the raccoon dog, we observed the initial stage of the expansion of this alien and invasive species. An abundant badger (and red fox) population may facilitate further increases in raccoon dog numbers through shelter provisioning. Increases in the number of cases of domestic dogs breeding in the wild points to a lack of control over stray/feral dogs due to legislative conditions. We may expect further growth of the population of stray/feral domestic dogs which will inevitably affect wildlife, including medium-sized carnivores. Overall, the community of medium-sized predators will be shaped by (both positive and agonistic) inter-species interactions. We may expect that with a growing density of the four carnivores, epidemics of sarcoptic mange may have an effect on population dynamics.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15010032/s1, Table S1. Results of the Mann-Whitney pairwise test (U test value and *p* value) for comparisons of the number of natal dens of the four carnivores recorded annually; Table S2. Results of the Mann-Whitney pairwise test (U test value and *p* value) for comparisons of the estimated density of badgers (adult and juveniles pooled together); Table S3. Results of the Mann-Whitney pairwise test (U test value and *p* value) for comparisons of the estimated density of badgers (juveniles); Table S4. Results of the Mann-Whitney pairwise test (U test value and *p* value) for comparisons of the recruitment of badgers (N juveniles per N of adults)

**Author Contributions:** Conceptualization, D.K.-G. and J.G.; methodology, D.K.-G. and J.G.; investigation: J.G. and D.K.-G.; data curation and statistical analysis, D.K.-G. and J.G.; writing—original draft preparation, D.K.-G. and J.G., visualization, D.K.-G. and J.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** The study received no funding.

**Institutional Review Board Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** We would like to thank employees of the Experimental Forest Station in Rogów: Dariusz Dałkowski for his help in gathering information on hunting bags and Krzysztof Małańczuk for sharing valuable information on breeding sites of the species under study. We would like to thank four anonymous reviewers for their valuable comments on the manuscript. We dedicate this paper to late professor Jacek Goszczyński, the pioneer of the medium-sized carnivore research in our study area.

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

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