Spatial analyses of GPS data of lynx reintroduced within the project POIS.02.04.00-00-0143/16 “The return of lynx to north-western Poland” with guidelines to the methodology of lynx reintroduction

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I. SPATIAL ANALYSES OF LYNX GPS DATA

1. Duration of lynx GPS-tracking

By 31.12.2021, 62 lynx were released into the wild (36 males and 26 females) (Table 1). Due to transmitter failure or animal death, only individuals, which were tracked for at least 60 days, were used in the further analyses (51 lynx: 32 males and 19 females). Duration of GPS-tracking of lynx included in the analyses ranged from 75 to 1029 days (mean – 385 days). In total, over 145,000 lynx locations were collected. The number of locations ranged from 540 to 7472 per individual (Fig. 1, Fig. 2).

Table 1. Number of lynx released into the wild within the project in 2019-2021.

Year	Number of released lynx		
	Females	Males	Total
2019	7	14	21
2020	10	19	29
2021	9	3	12
Total	26	36	62

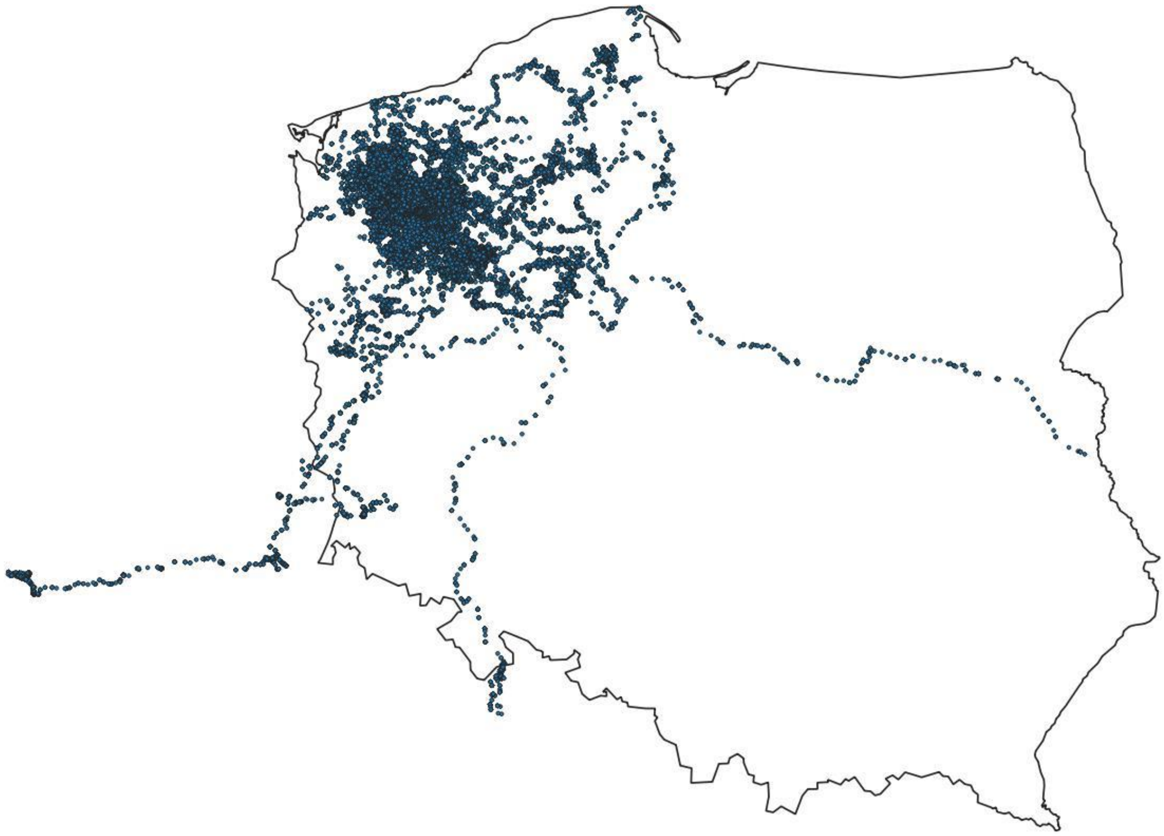

Fig. 1. Distribution of locations of lynx reintroduced under the project in north-western Poland in 2019-2021.

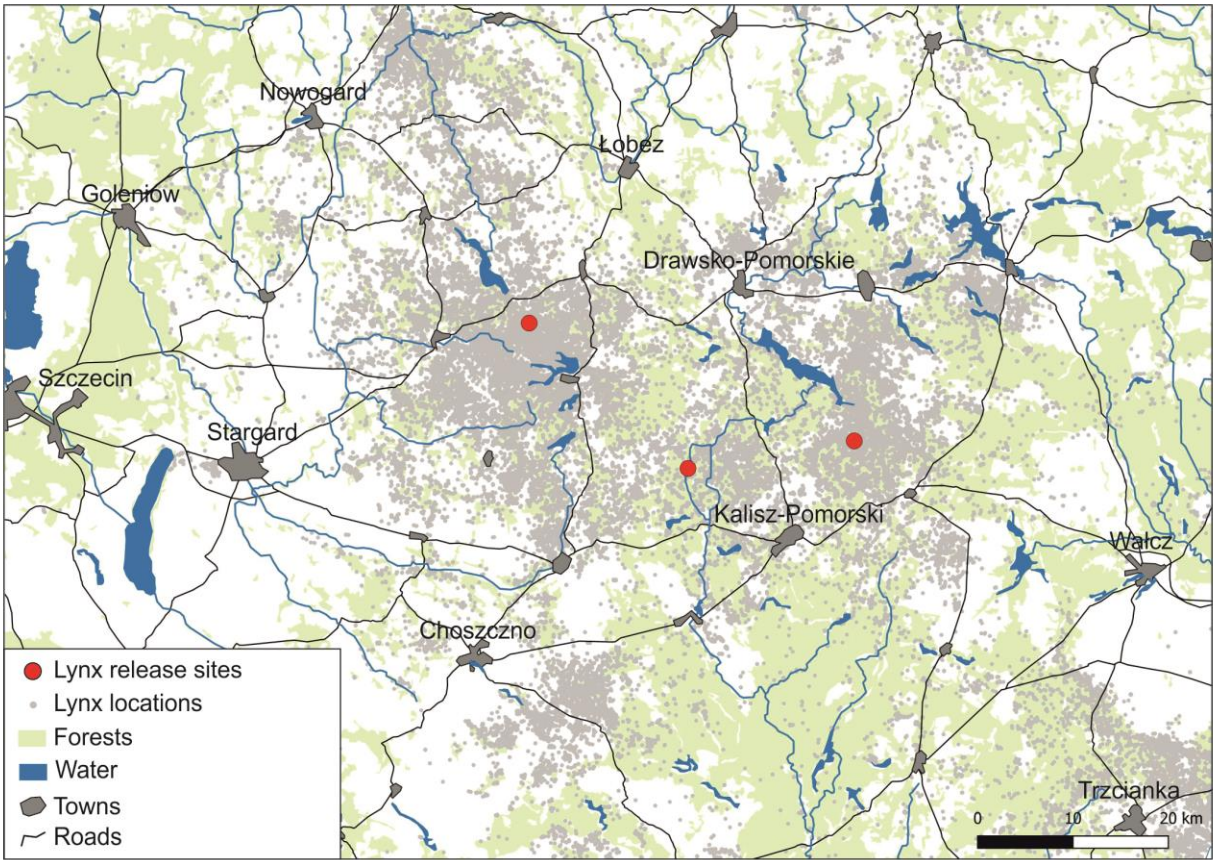

Fig. 2. Location of lynx release sites.

2. Distance of lynx movements

The distances of lynx movements in different periods of GPS data collection (month, season, year) were calculated as sums of distances between consecutive locations of individual lynx. Such estimation of movement distances is strongly dependent on the number of lynx locations per day (the more locations, the longer movement distance). In the case of lynx reintroduced in north-western Poland, locations were collected at a frequency of 8 locations per day, therefore it should be assumed that the calculated distances covered by lynx do not reflect the real movement distances and they have to be interpreted as the minimum movement distances.

Distance of lynx movements in all analysed periods expressed high individual variability. For monthly periods, movement distance ranged from 5 to 418 km. The longest monthly movements were observed in January and March, whereas the shortest in June and September (Fig. 3). On average, males covered longer distances than females (135.7 and 93.5 km, respectively). It is worth noting that males made the longest monthly movements between January and March (mating period) (168-243 km). Females in these months covered about 128 km. On the other hand, the shortest monthly movements were recorded for females in May-July (the period of rearing young, 58-72 km), whereas males travelled 77-114 km.

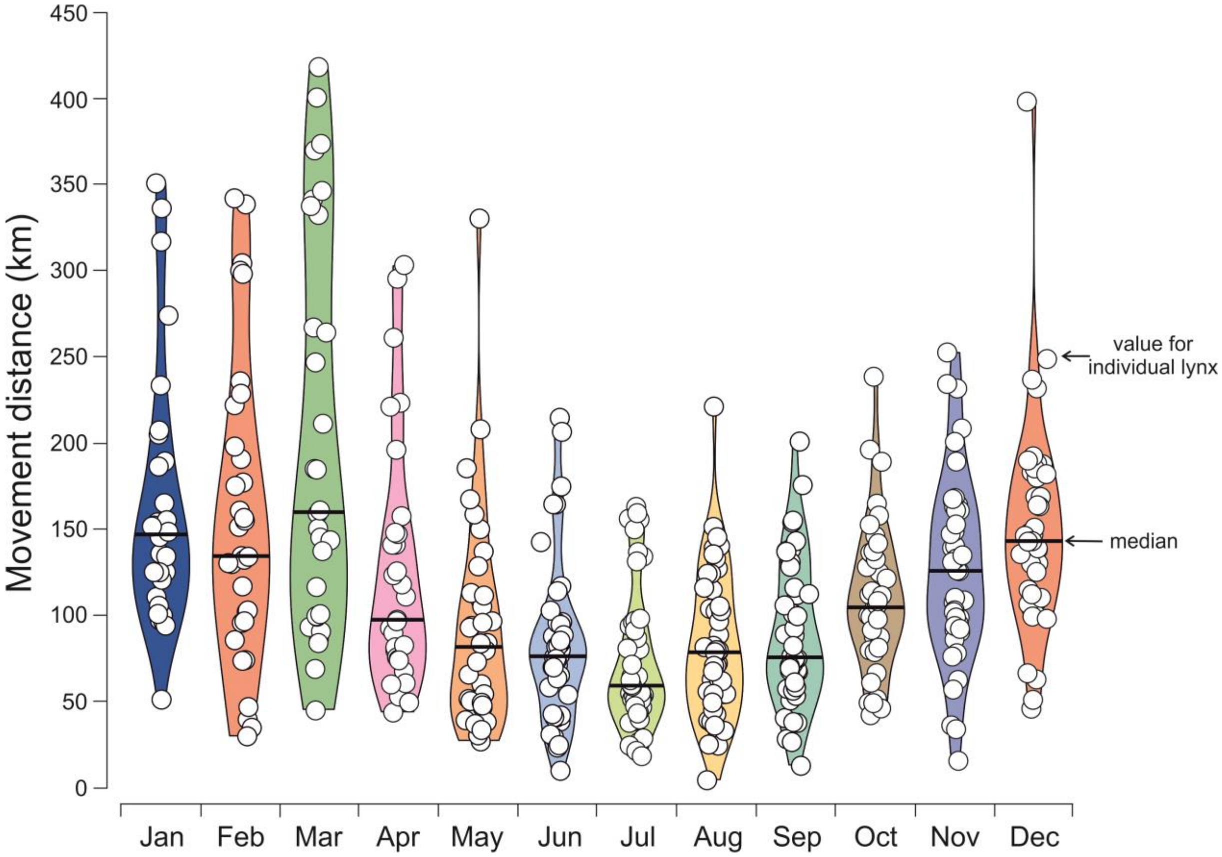

Fig. 3. Monthly movement distances of lynx.

Lynx showed different mobility with respect to the time elapsed after their release into the wild. Median movement distance initially increased with time after animal release (from 1 to 11 months) and then gradually decreased. After about 12 months from release a stabilization of the median movement distance was observed (Fig. 4).

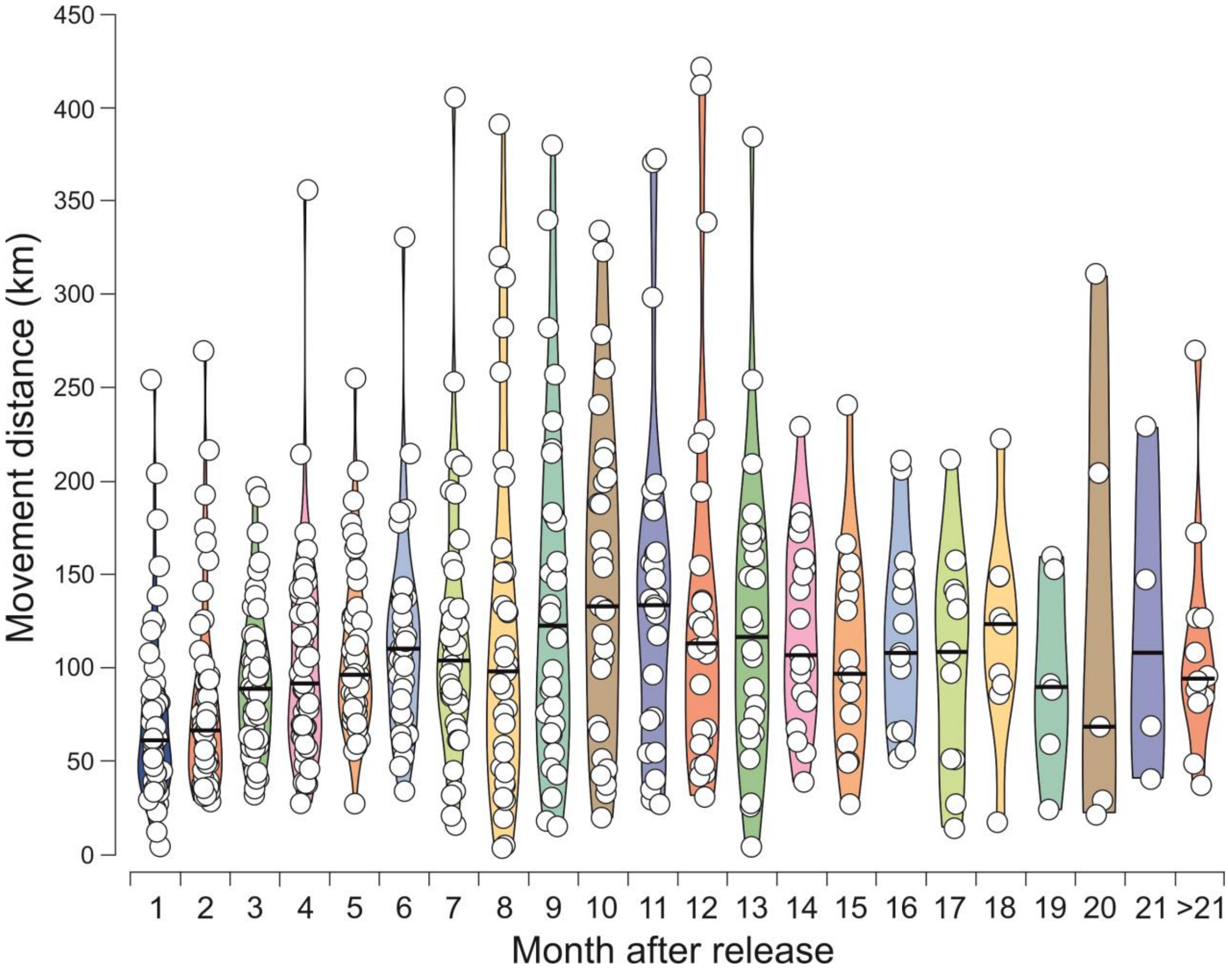

Fig. 4. Movement distance of lynx in consecutive months after their release into the wild.

Winter (December-February) was the period when lynx showed the highest mobility (maximum over 850 km), whereas lynx were least mobile in summer (June-August) (Fig. 5). The differences between seasons were particularly pronounced in the case of males, which movement covered an average of 497 and 507 km in winter and spring, and 272 km in summer. Females, on the other hand, moved much shorter distances in these seasons, 351, 248 and 208 km, respectively.

The variation in movement distances of lynx reintroduced within the project, both monthly and seasonally, reflects the trends observed in wild lynx (e.g. in the Białowieża Forest). Males migrate long distances during the mating period (January-March), whereas females are characterised by particularly limited mobility during the period of rearing young (May-July) (Jędrzejewski et al. 2002).

On an annual basis (24 individuals), lynx travelled between 498 and 2391 km. Males covered on average greater distance than females during the year, 1622 and 987 km, respectively.

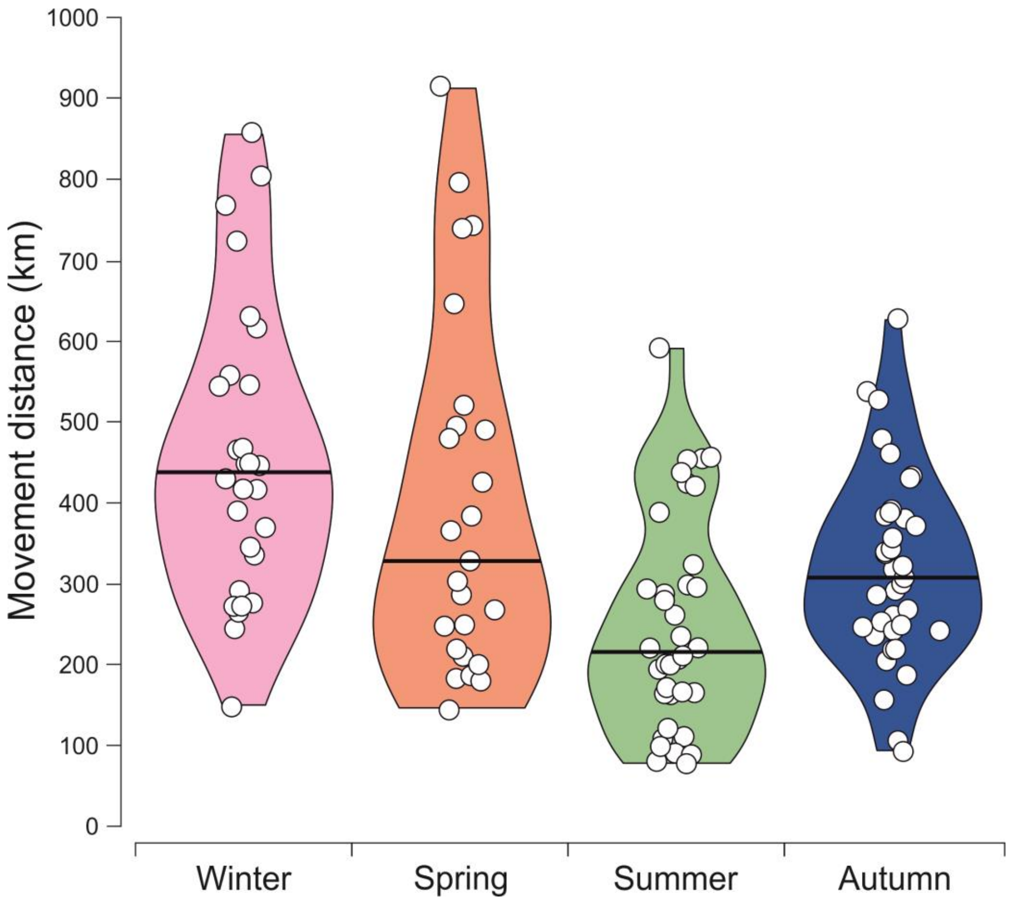

Fig. 5. Distance of seasonal movements of lynx.

The farthest lynx dispersal, outside Poland to Germany and the Czech Republic, took place in the initial period of the project, i.e. within two years of the release of the first lynx into the wild. During this period there were significantly more males released into the wild. Distant movements outside the project area almost stopped when the number of released lynxes approached 30. This seems to be in line with the observations in the Swiss Alps and the Jura Mountains, where it was found that lynx dispersal distance decreased with increasing population density (Zimmermann et al. 2007).

3. The size of areas utilized by lynx

a) Minimum Convex Polygon

Minimum Convex Polygon (MPC 95%) method was used to estimate the size of the areas covered by lynx movements after their release to the wild. The size of these areas varied considerably among lynx and months. The monthly individual range size reached up to 11258 km^2. The largest median ranges were observed in January and December, the smallest in July and August. (Fig. 6). The average area covered by male movements was larger than that of females (394.5 and 122 km^2, respectively).

It should be noted, however, that these values do not reflect the actual home ranges used by wild lynx in natural, stable populations. Animals released into the wild in an environment where no individuals of this species were previously present do not have the necessary cues to create a biologically determined spatial structure of the population. Therefore, our use of the term "range" or "home range" has a conventional meaning. Moreover, the estimated values apply to all individuals, irrespective of their individual efficiency in searching for and establishing an individual home range. Indeed, lynx were characterised by a large variation in the time of adaptation to natural conditions. Some individuals after release made very long movements before settling down for a longer period. This period, therefore, greatly overestimates the size of the area. Nevertheless, it is difficult to determine the length of the adaptation process common to all lynx which could be appropriate to estimate the true size of the individual home ranges once they were established. Such an attempt was made in Chapter 4.

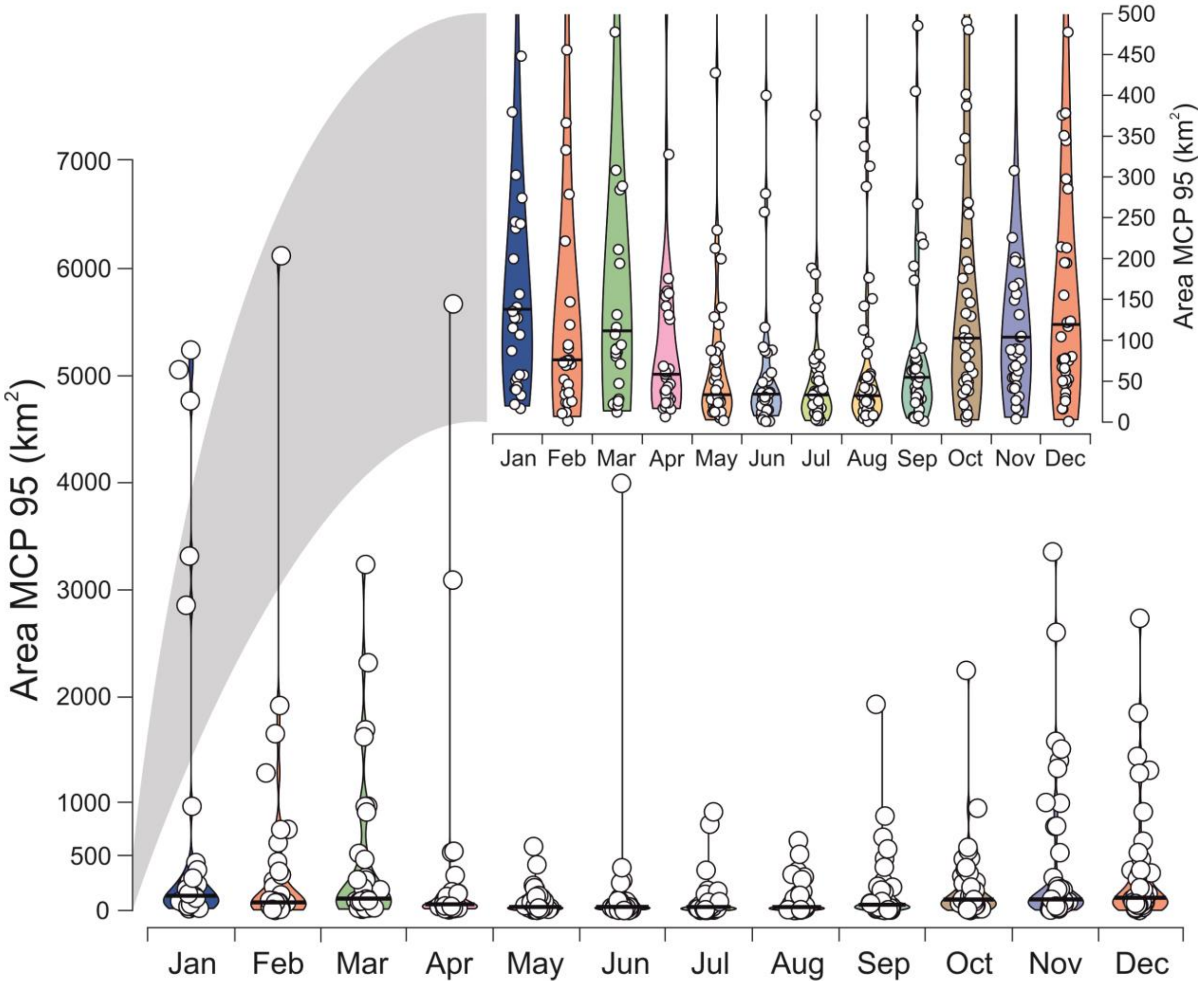

Fig. 6. The size of monthly ranges of lynx estimated using Minimum Convex Polygon (95%) method.

The median size of monthly ranges increased with time from lynx release into the wild (to 7-12 months). This increase is probably due to exploratory movements during the lynx's adaptation to the environment. From the 12th month onwards, the median monthly range size stabilized at about 50 km^2 (Fig. 7). This may suggest that the 1-year period is the time when the mechanisms that shape the spatial population structure of new predator population begin to take effect.

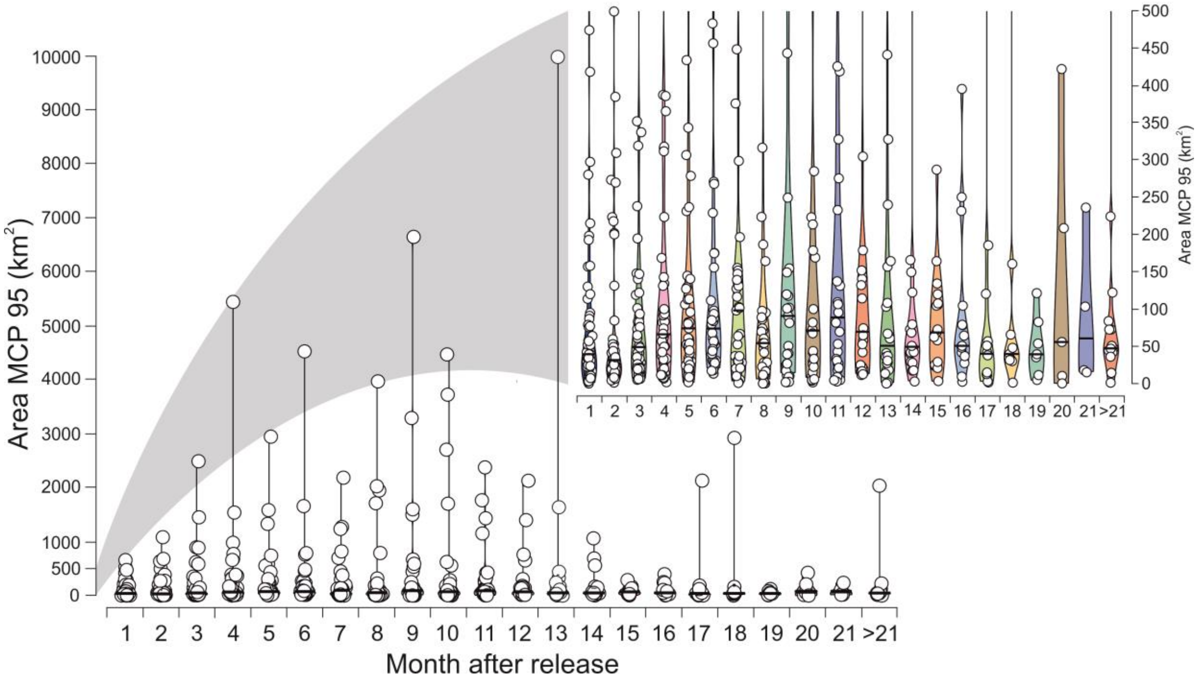

Fig. 7. The size of individual ranges in consecutive months after lynx release into the wild estimated using Minimum Convex Polygon (95%) method.

Lynx occupied the largest seasonal ranges in winter, whereas summer was a period with the smallest home ranges (Fig. 8). During winter males had the most extensive movements, which covered an area averaging 3437 km^2. Females used only the area of 252 km^2 during this period. It is worth noting that this seasonal variation corresponds exactly to the variation observed in wild lynx, determined by the biological cycle of this species (e.g. Schmidt et al. 1997). Namely, there is a mating period in winter, during which lynx (especially males) express increased activity moving long distances in search of partners (Jędrzejewski et al. 2002). The size of areas covered by lynx annually ranged from 96 to 43262 km^2. However, the average size of these areas was 5619.6 in males and 1981.2 km^2 in females.

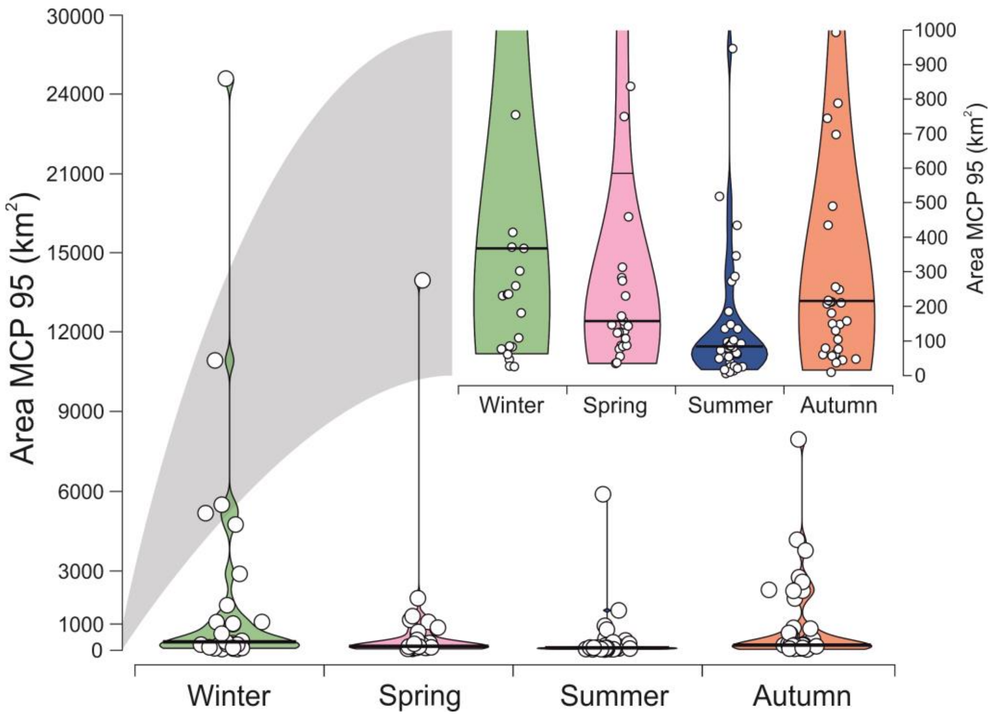

Fig. 8. The size of lynx seasonal ranges estimated using Minimum Convex Polygon (95%) method.

b) Kernel Density Estimation

Additionally, the size of areas used by lynx was estimated using the Kernel Density Estimation (KDE 95%) method. Compared to the Minimum Convex Polygon method, the KDE method is less susceptible to localization errors, shape of the used area and extreme localizations, thus it more accurately represents the animal home ranges and gives more precise estimates of their size (Börger et al. 2006). The median size of area covered by lynx monthly estimated using Kernel Density Estimation (KDE 95%) method was highest in January and December, and lowest in July and May. The size of monthly lynx ranges ranged from 6 do 388 km^2 (Fig. 9). Similarly to MCP method, the areas covered monthly by males was larger than those of females (84.7 and 57.7 km^2, respectively).

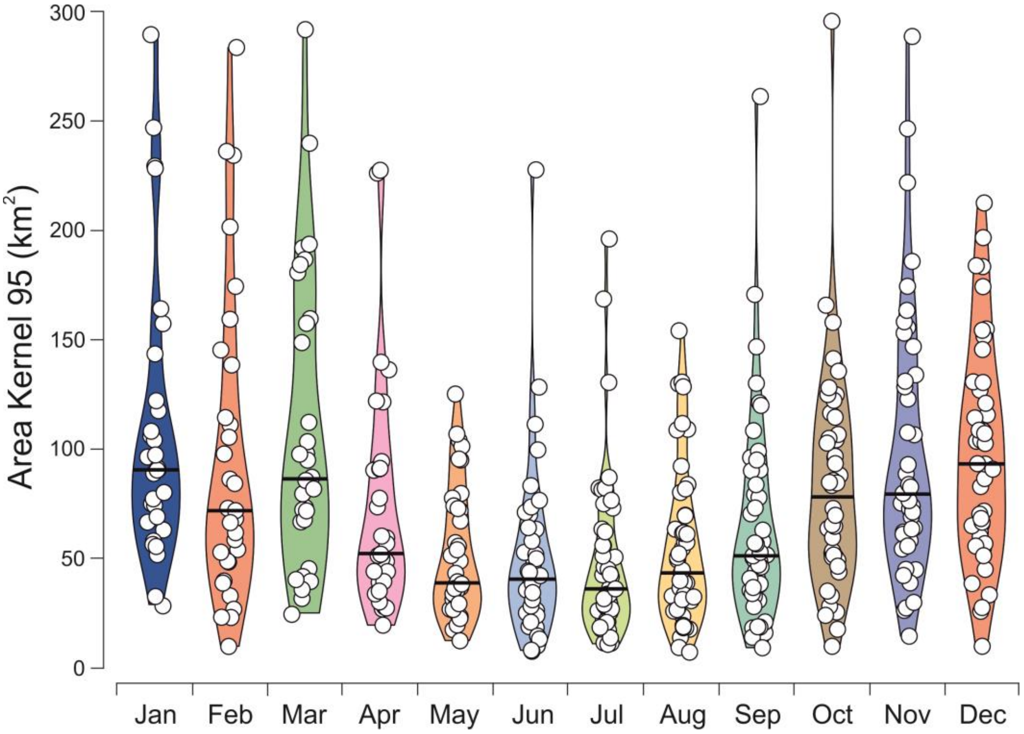

Fig. 9. The size of lynx monthly ranges estimated using Kernel Density Estimation (95%) method.

The size of monthly home ranges increased with time from lynx release into the wild (up to the 10th month). From the 13th month a stabilization of the median size of monthly home range was observed (at around 50 km^2; Fig. 10).

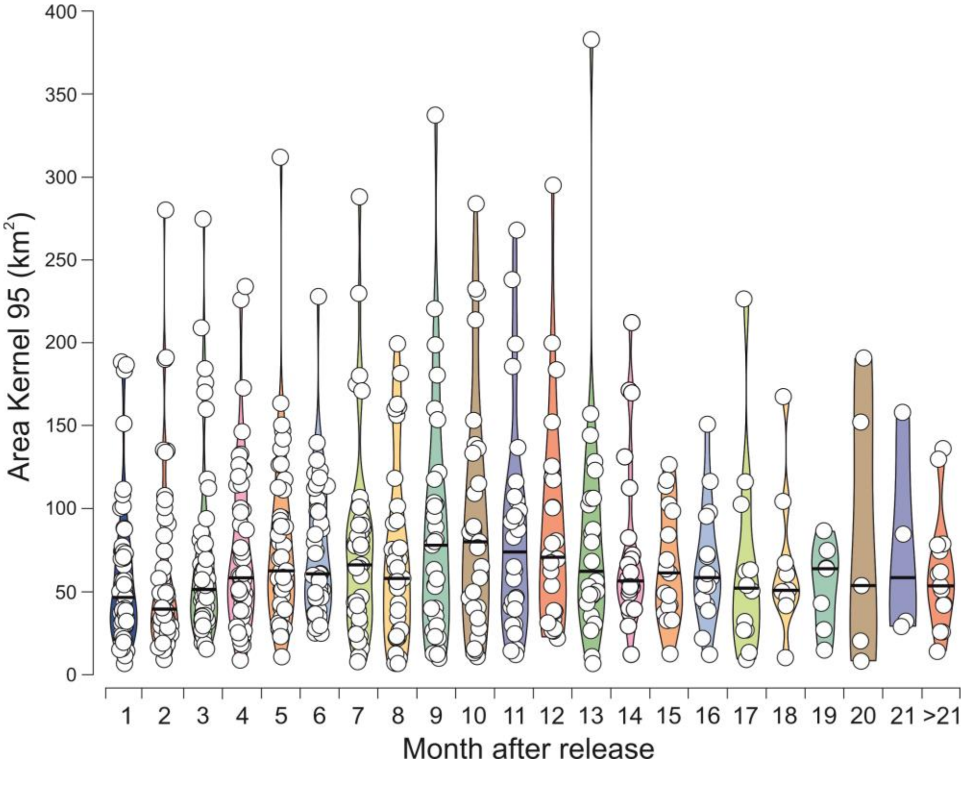

Fig. 10. The size of lynx ranges in consecutive months after their release into the wild estimated using Kernel Density Estimation (95%) method.

The median size of lynx ranges was the highest in winter and autumn, whereas summer was the period when lynx occupied the smallest area (Fig. 11). Seasonal ranges estimated using the KDE method, similarly to the MCP method, were greater in males than in females. However, the size of the KDE ranges was many times lower. Therefore, although mean seasonal range was highest in winter (254 km^2; in females it was 130 km^2 at that time), its size estimated using this method was 13 times lower than calculated using MCP method. This difference indicates, on the one hand, that during winter lynx moved far from the region of their most frequent use (which is consistent with their reproductive cycle) and, on the other hand, that the values estimated with the KDE method may better approximate range sizes observed in natural populations of this species.

The median size of area occupied by lynx annually ranged from 96 to 1173 km^2. The mean size of annual male ranges was 502.4 km^2, whereas in females it was more than twice smaller – 231 km^2.

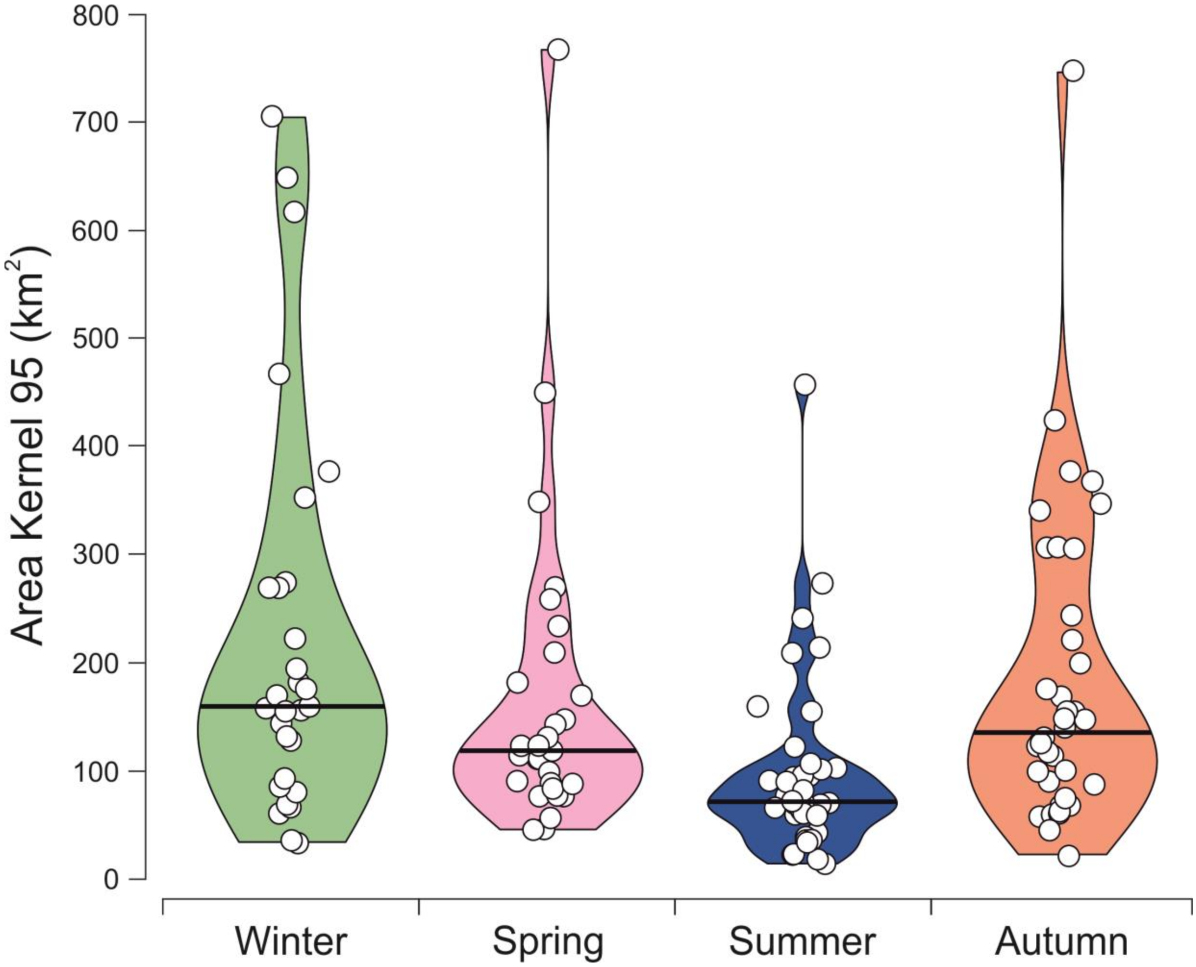

Fig. 11. The size of lynx seasonal ranges estimated using Kernel Density Estimation (95%) method.

4. Individual home range size

Of all the lynx included in the analysis of the space use, 26 individuals (12 females and 14 males) were selected, which were followed long enough to distinguish a period of stability in the data on their movements, indicating the establishment of individual home range. Duration of this period, which averaged 393 days for males and 359 days for females, had no effect on the size of the estimated ranges (MCP: $R = 0.21$, $P = 0.30$; KDE: $R = 0.23$, $P = 0.26$).

The mean home range size estimated using MCP method for all stationary lynx was 304 km^2, whereas using KDE method 313 km^2. Males utilized larger home ranges than females, both for MCP (416 and 201 km^2, respectively) and KDE method (401 and 225 km^2) (Fig. 12, 13).

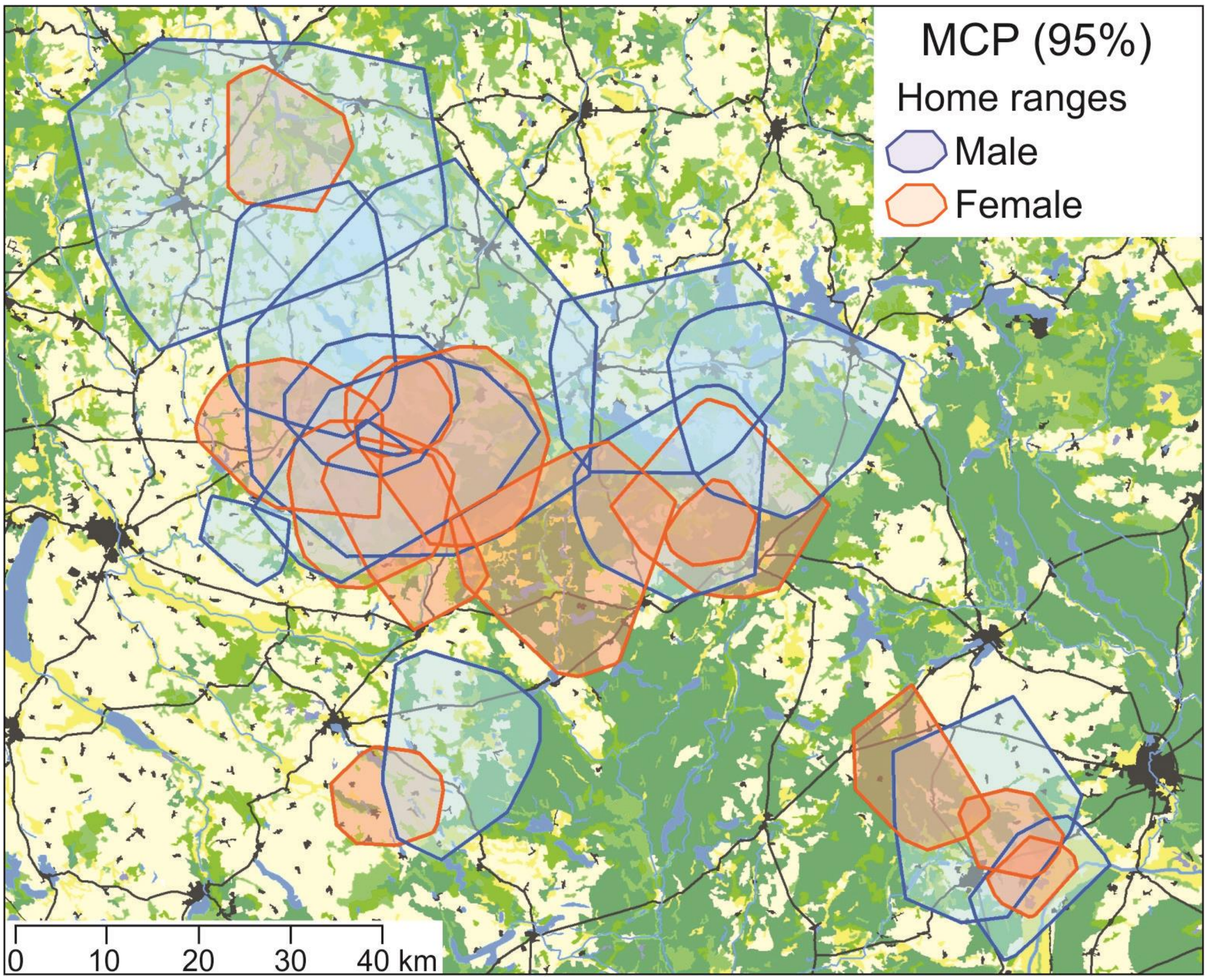

Fig. 12. Distribution of lynx home ranges estimated using Minimum Convex Polygon (MCP 95%).

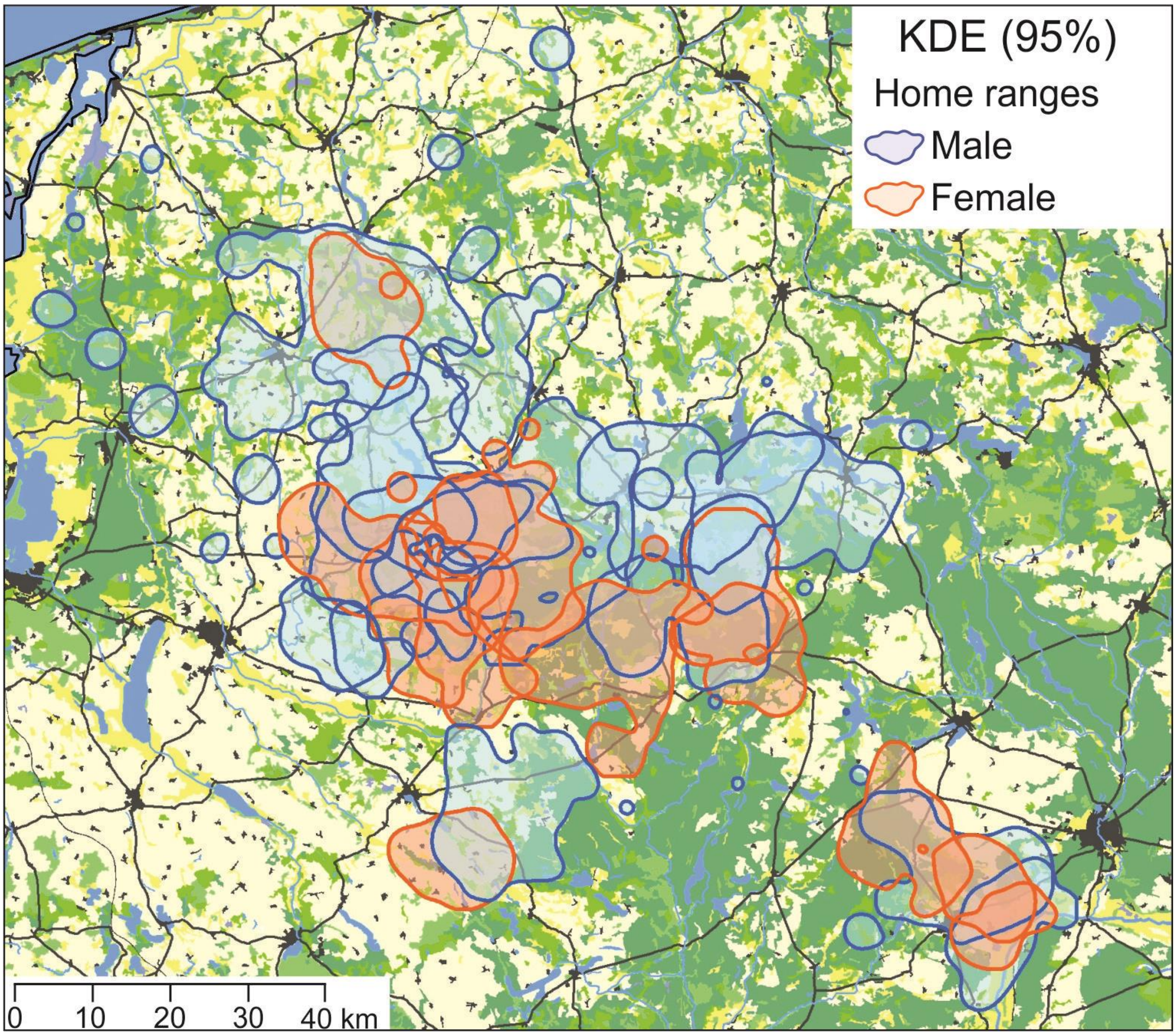

Fig. 13. Distribution of lynx home ranges estimated using Kernel Density Estimation (KDE 95%) method. KDE method does not allow to visually distinguish individual home ranges plotted on the same map, because they are often formed by several separate parts corresponding to areas with the highest density of locations.

5. Overlap of lynx home ranges

Analyses of lynx home range overlap were made using locations of individuals which home ranges expressed spatio-temporal stationarity, i.e. those lynx which after release and initial movements did not move long distances for at least two months. Home ranges of these individuals were estimated with Minimum Convex Polygon (95%) method. Due to variable tracking time of individual lynx, the degree of home range overlap was calculated only for period when locations of both individuals in the considered pair were available. Among home range pairs, which expressed spatial overlap, the most common were mixed pairs (male-female: 56%), whereas home range overlap of the same sex was less frequent (females: 25%, males: 19%). An overlap of lynx home ranges was highly variable: from 0.1 to 79.8%. The highest home range overlap was indicated for neighbouring individuals of different sex (mean = 39.1%), and the lowest for females (mean = 11.1%), (Fig. 14).

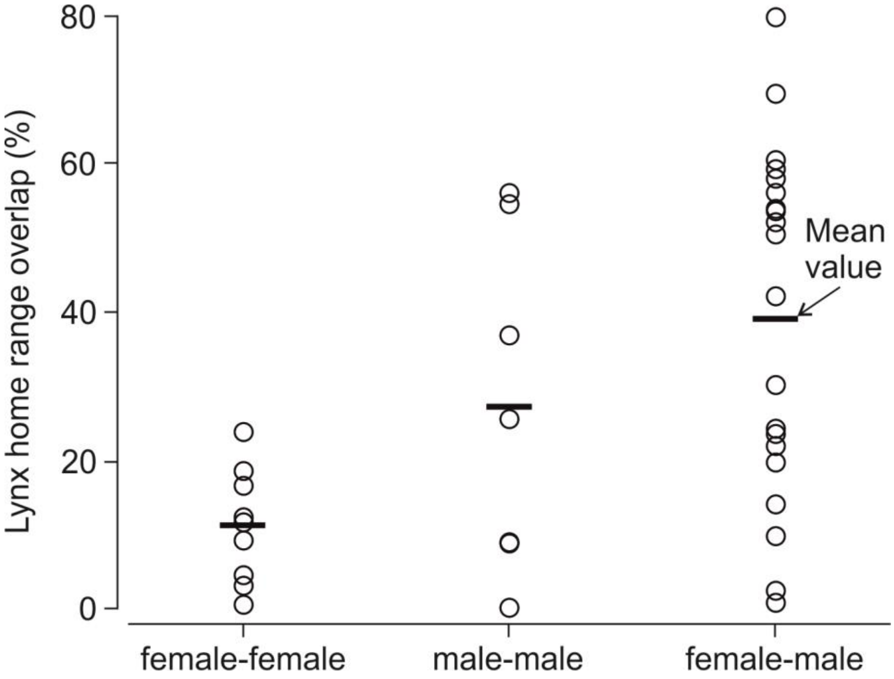

Fig. 14. Lynx home range overlap.

6. Habitat selection of lynx

The analyses of lynx habitat selection were made at two different spatial scales: landscape (large-scale model) and individual home range (micro-scale model). In addition, within the estimated home ranges the habitat selection was estimated within forested areas (forest model). To describe lynx habitat selection, utilized habitats were compared with habitats in random locations. In analyses we used the following environmental and anthropogenic variables: forest cover (Global Land Cover, 2020), forest fragmentation (Global Land Cover, 2020), roe deer population density (Forest Data Bank, 2019-2021), distance to roads (Topographic Objects Database, 2019), distance to built-up areas (Topographic Objects Database, 2019), distance to the forest edge (Global Land Cover, 2020), tree cover (Copernicus Observation System, 2018), undergrowth cover (Forest Data Bank, 2014-2020).

a) Large-scale model

Large-scale model was aimed at identifying environmental and anthropogenic variables determining location of lynx home ranges at landscape level. The variables considered were: forest cover, forest fragmentation, roe deer population density, distance to roads, distance to built-up areas. The highest probability (above 50%) of area being inhabited by lynx (having stationary home range) was indicated for landscapes with forest cover ranging from 18 to 90% (Fig. 15). Lynx most often located their home ranges in areas with intermediate fragmentation of forests – areas with forest fragmentation index ranging from 0.7 to 2.4 had more than 50% probability of being inhabited by lynx (Fig. 15). Moreover, when settling a new area lynx preferred areas with high roe deer population densities – above 2 individuals per 1 km^2. The highest probability of area being inhabited by lynx was observed in places where roe deer population density was estimated at about 5 individuals per 1 km^2 (Fig. 14). Lynx avoided highly urbanised areas. The probability of area being inhabited by lynx decreased with decreasing distance to built-up areas and main roads (Fig. 15).

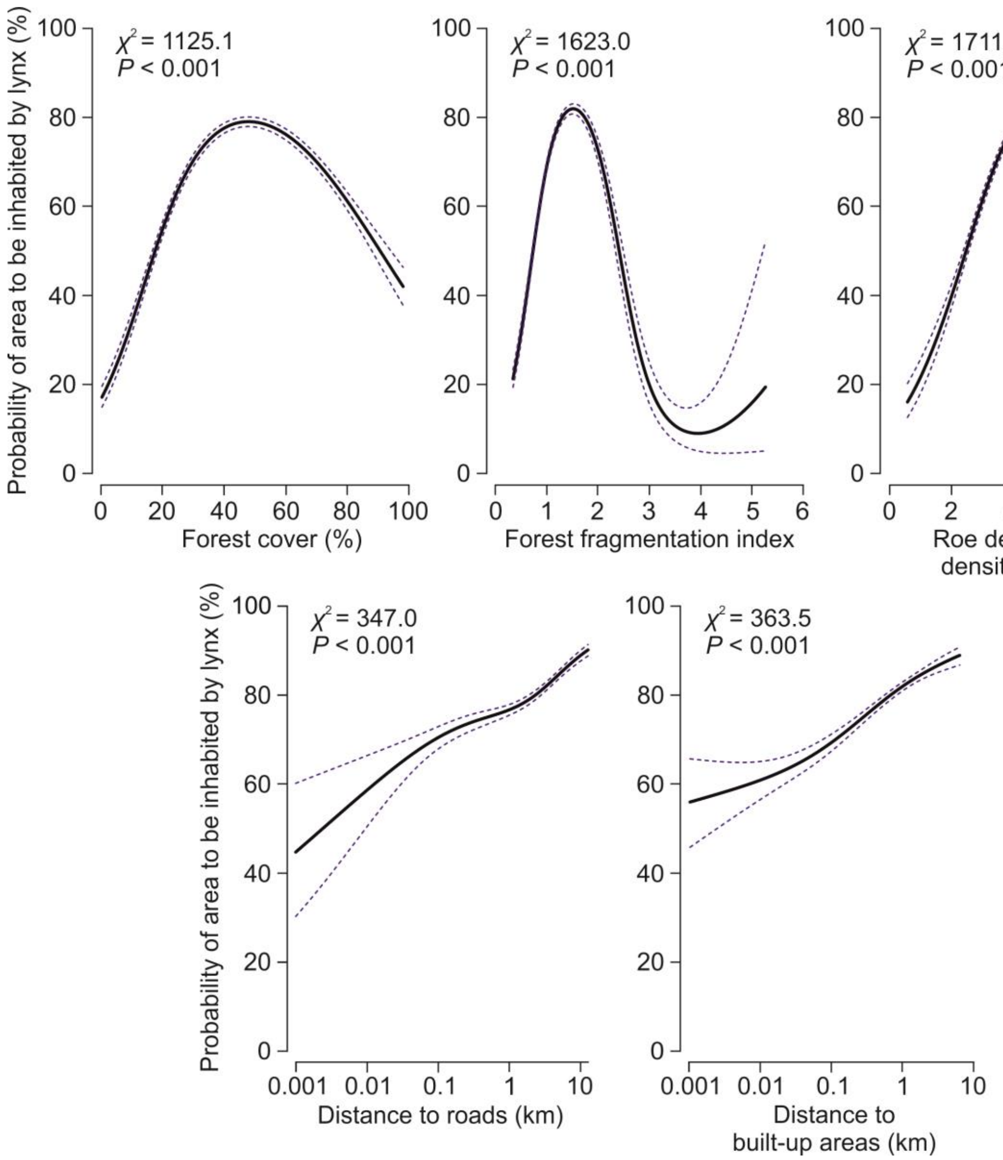

Fig. 15. Habitat selection of lynx at landscape level – results of a large-scale model. Distance to roads and built-up areas are presented on a logarithmic scale.

b) Micro-scale model

The aim of micro-scale model was to indicate habitat selection of lynx within occupied home ranges. The micro-scale model was calculated using GPS-tracking data of lynx, whose home ranges were stationary (26 lynx). The variables used in the analyses were: distance to the forest edge line, distance to roads and distance to built-up areas. Distance to the forest edge was measured for both locations outside (negative value) and inside forests (positive value). Within home ranges lynx preferred areas located in the closest vicinity to the forest edge (both outside and inside forests). The highest (over 40%) probability of lynx occurrence was indicated between -0.26 and 0.33 km from the forest edge (Fig. 16). Lynx avoided areas located near roads and, to a lesser extent, built-up areas. The probability of lynx occurrence increased with increasing distance from the main and secondary roads. Lynx showed the highest preference (over 50% probability of occurrence) for areas located between 0.1 and 4.0 km from the nearest human settlement (Fig. 16).

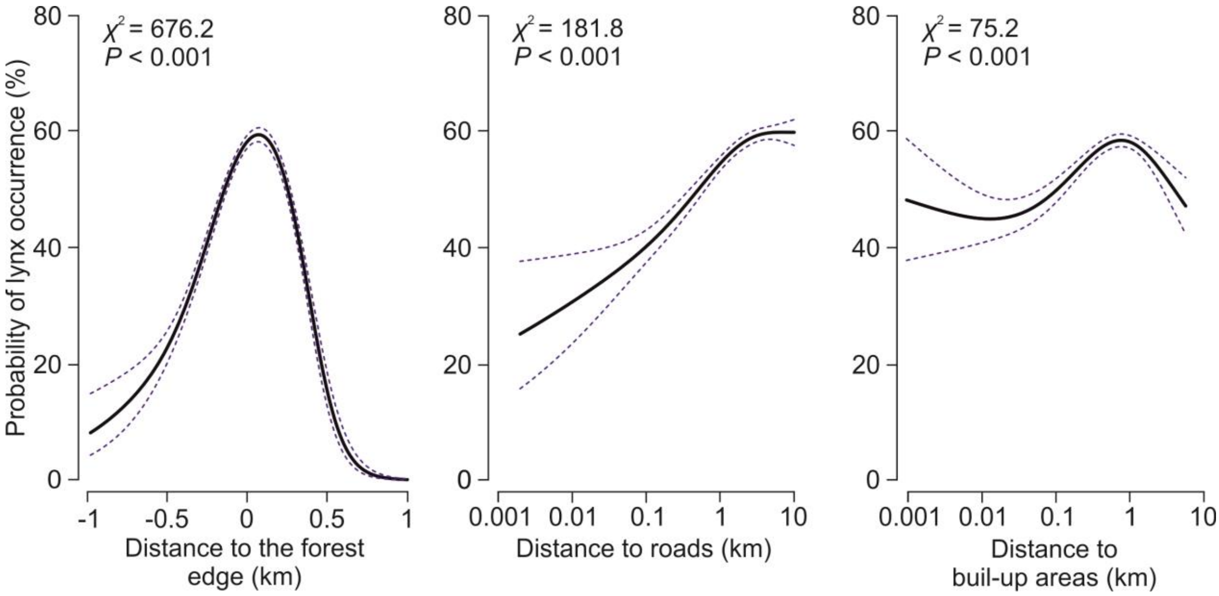

Fig. 16. Habitat selection of lynx within their home ranges – results of a micro-scale model. Distance to roads and human settlements was presented on a logarithmic scale.

c) Forest model

Given the significant role of forested areas in lynx habitat selection at landscape level an additional micro-scale analysis was made. This analysis focused on forests habitats located within lynx home ranges and was aimed at indicating if forest structure traits: distance to the forest edge, tree cover and undergrowth cover affected habitat utilization by lynx. When using forest habitats, lynx preferred ecotone areas, i.e. located near the forest edge. With increasing distance to the forest edge probability of lynx occurrence remarkably decreased (Fig. 17).

Lynx also preferred forests characterised by a low tree cover, i.e. forest stand fragments abundant in glades and gaps. The probability of lynx occurrence clearly decreased with increasing tree cover above 60%. The probability of lynx occurrence was also correlated with the undergrowth cover – with increasing share of undergrowth the probability of lynx occurrence increased. The highest probability of lynx occurrence was observed in forests with undergrowth cover above 40% (Fig. 17).

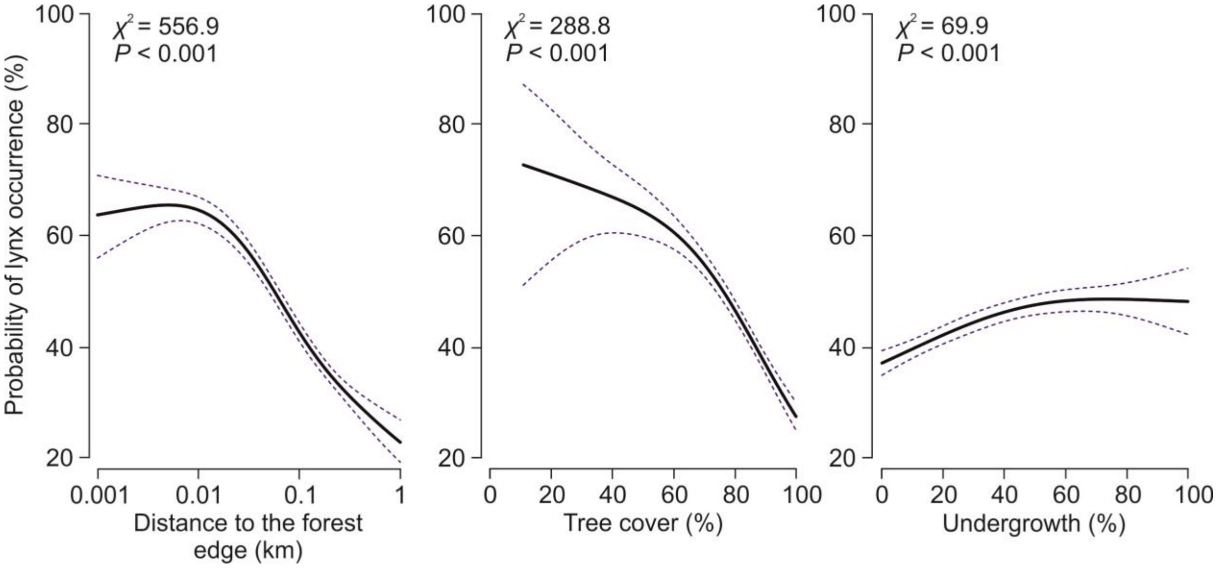

Fig. 17. Habitat selection of lynx within their home ranges – results of a forest model. Distance to the forest edge was presented on a logarithmic scale.

7. The influence of anthropogenic and natural environmental factors on the implementation of reintroduction programme

In order to determine how anthropogenic and natural environmental factors affected the location of lynx home ranges and utilization of home ranges by lynx, the results of habitat suitability models (macro-scale and micro-scale models) prepared for the lynx reintroduction programme (Górny et al. 2017) were compared with lynx habitat selection estimated on the basis of collected telemetry data. Habitat suitability models prepared before the lynx release into the wild, aimed at identifying the most suitable areas for lynx reintroduction in western and north-western Poland. Models took into account, on different spatial scales, both natural environmental (forest cover, distance to the forest edge, undergrowth cover, forest habitat type, age of the forest stands) and anthropogenic factors (share of built-up areas, density of public roads). The results of the comparative analysis showed that lynx at landscape level mainly selected areas of intermediate suitability indicated by the macro-scale model. The decrease in the probability of area being inhabited by lynx at high suitability values indicated by the macro-scale model can suggest that there are still sites of high environmental quality in reintroduction area that may be inhabited by lynx in the future (Fig. 18).

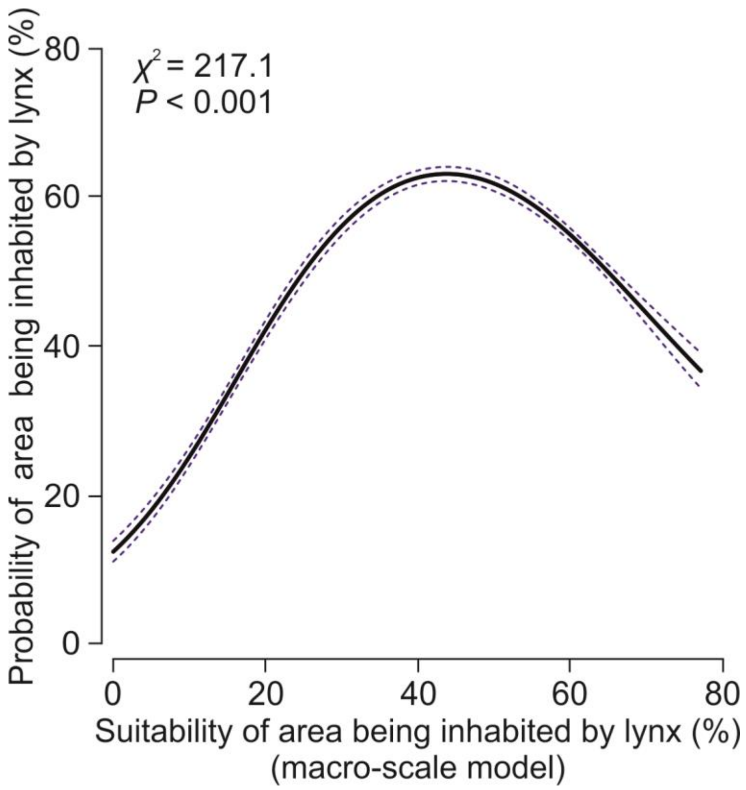

Fig. 18. Concordance between the predictions of macro-scale habitat suitability model for lynx and the probability of area being inhabited by lynx.

Within individual home ranges, lynx utilized habitats as predicted by the micro-scale model. The probability of lynx occurrence increased with increasing suitability of habitats indicated by the micro-scale model. In other words, when utilizing habitats located within their stationary home ranges, lynx preferred areas indicated by the micro-scale model as those of the highest suitability (Fig. 19).

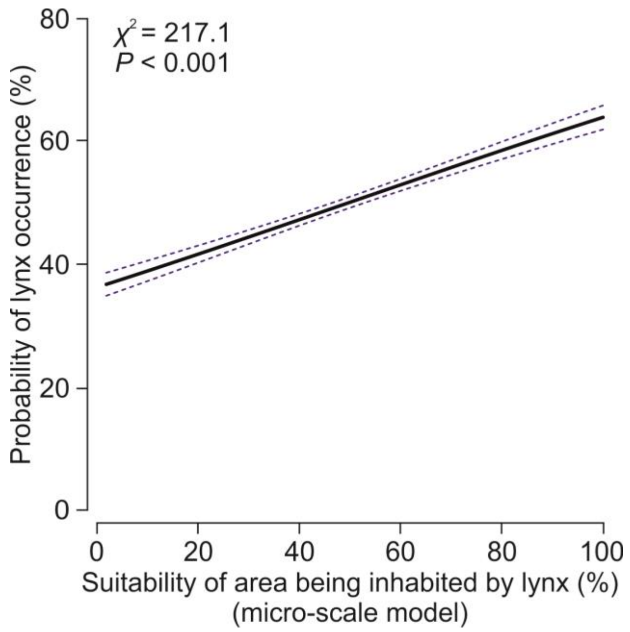

Fig. 19. Concordance between the predictions of micro-scale habitat suitability model for lynx and the probability of lynx occurrence within individual home range.

8. Habitat Suitability Models

The results of habitat suitability modelling (large-scale model, micro-scale model and forest model) are presented in Chapter 6 of this report. The predictions of the above-described models were also used to generate habitat suitability maps for lynx in north-western Poland. For large-scale model, the extent of the map was limited to the area estimated using Minimum Convex Polygon (95%) for lynx locations using habitats in north-western Poland (Fig. 20). In the case of micro-scale and forest models the map extent encompassed an area occupied by home ranges of resident lynx (Fig. 21, Fig. 22).

The large-scale model shows that areas where lynx stabilized their home ranges after an initial adaptation to natural environment were characterized by the highest habitat suitability in terms of the environmental variables included in the model. In other words, this model confirmed that the area designated for lynx reintroduction meets basic conditions relevant to the environmental requirements of the species. At the same time, habitat suitability map indicates that many areas in north-western Poland that meet these conditions to a large extent, have not yet been inhabited by lynx (Fig. 20).

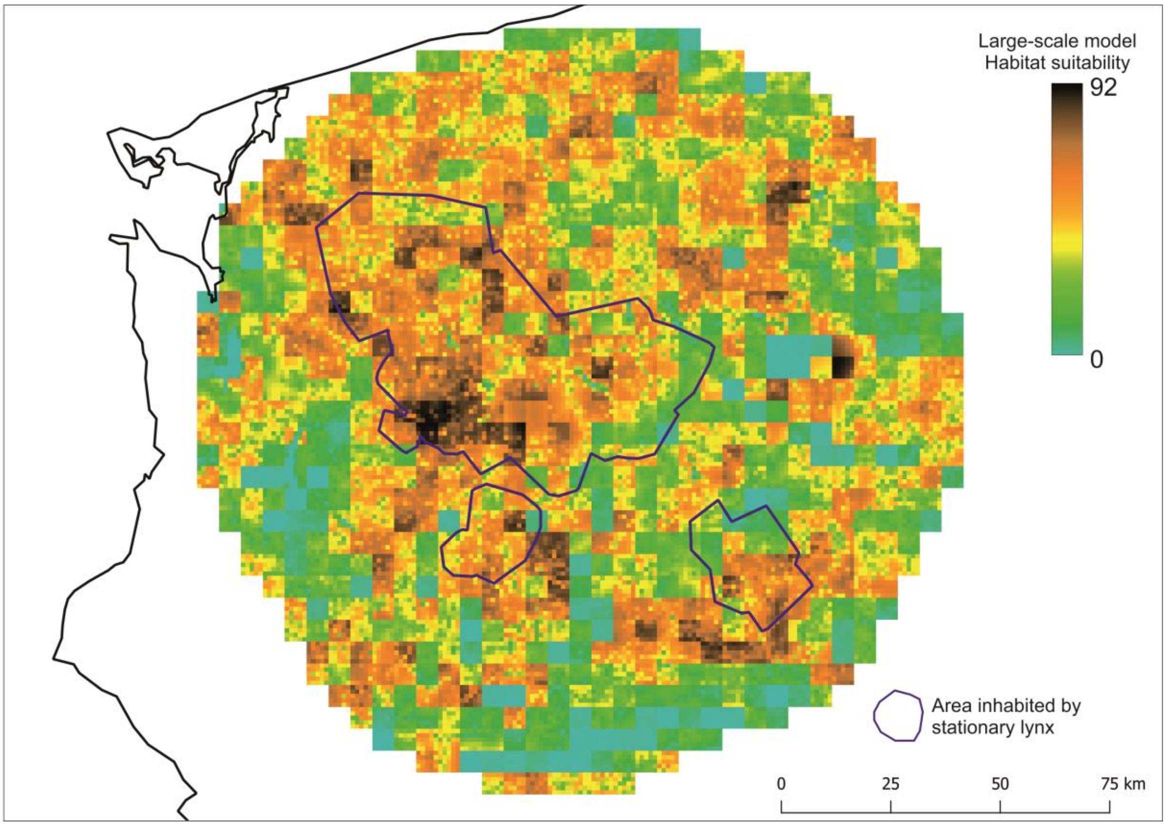

Fig. 20. Distribution of habitats suitable for lynx in north-eastern Poland – results of a large-scale model.

The micro-scale model presented in Fig. 21, calculated for areas occupied by home ranges of reintroduced lynx, indicated large spatial variation in the habitat quality. Yet, most habitats within these areas were of medium to high quality – the most suitable habitats (over 50%) covered 47.3% of the lynx territories. Areas of the lowest suitability were mainly located near roads and built-up areas (Fig. 21).

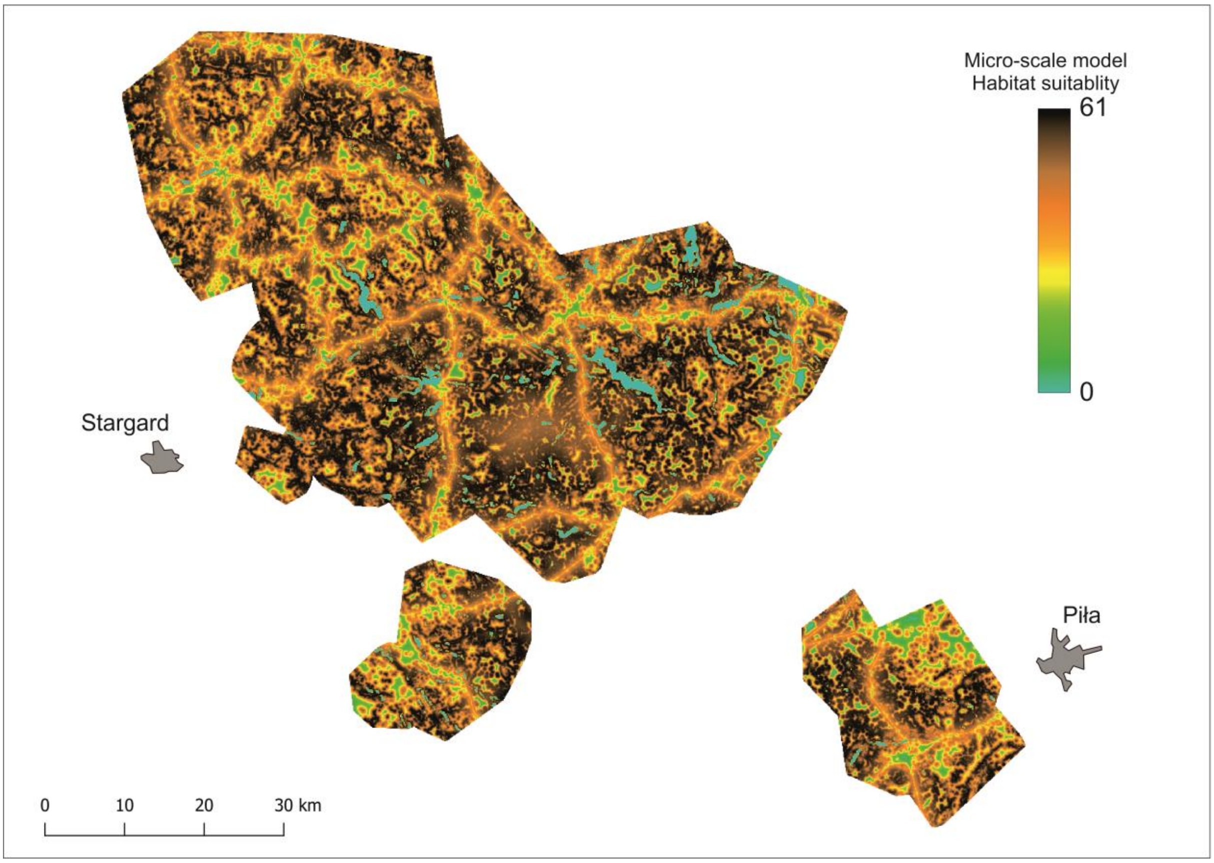

Fig. 21. Distribution of habitats suitable for lynx within their home ranges – results of a micro-scale model.

The map of the micro-scale model taking into account the forest structure (forest model) shows that lynx, when utilizing forest habitats within their home ranges, use a relatively small share of their available area. Habitats of the highest suitability (above 50%) in terms of distance to the forest edge, tree cover and undergrowth availability covered only 20.6% of the forest area within lynx home ranges (Fig. 22). This may indicate that most suitable habitats are highly fragmented and spatially dispersed and, on the other hand, that captive-born lynx quickly adapt to the natural environment while using it according to the species biological requirements observed in natural populations (Podgórski et al. 2008).

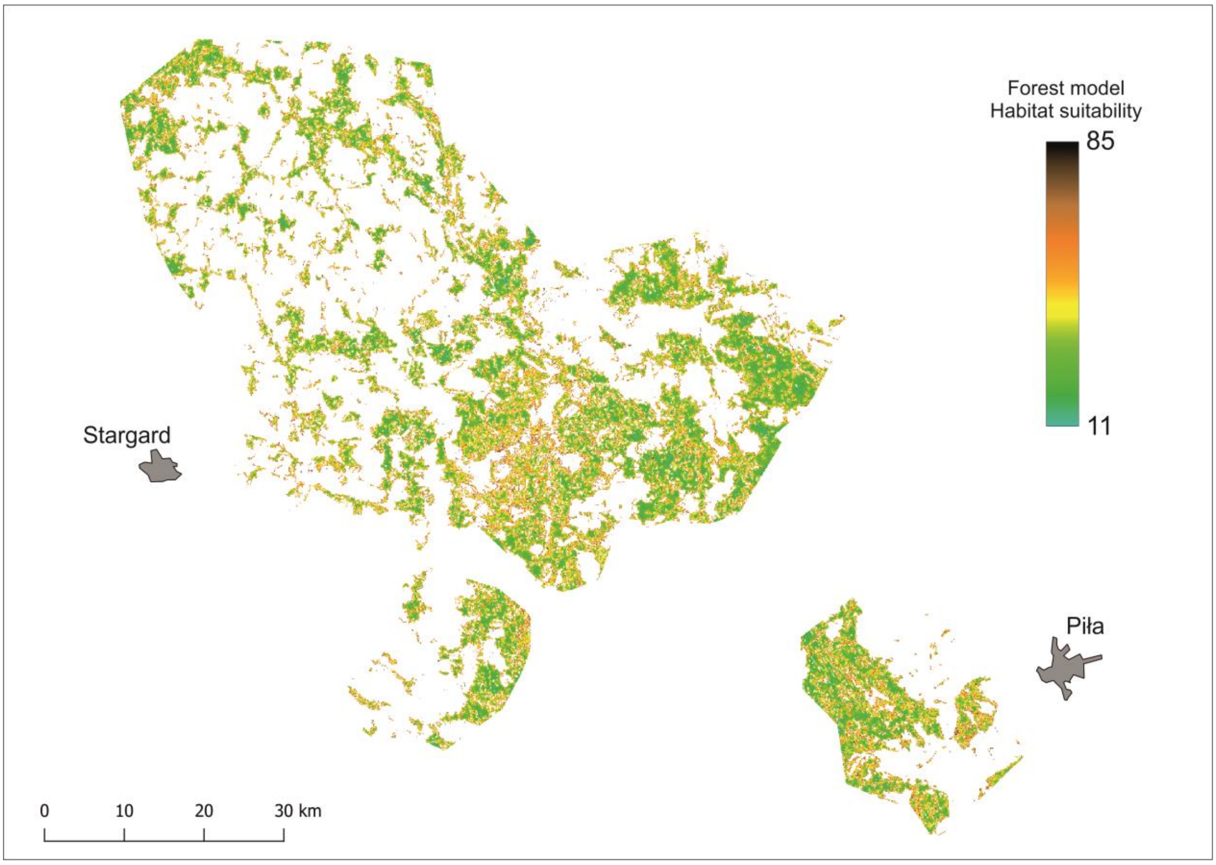

Fig. 22. Distribution of forest habitats suitable for lynx located within their home ranges – results of a forest model.

9. Lynx prey

A total of 334 wild prey of 53 reintroduced lynx were found by 31.12.2021 (Fig. 23). Prey included both mammals and birds. Lynx most often preyed on roe deer (82.9%), whereas the share of other prey did not exceed 4% (Fig. 24). However, it should be highlighted that the found prey do not fully reflect the real species composition of the food obtained by lynxes. The search and identification of lynx prey was carried out during the project on the basis of the analysis of telemetry data, which allows to find large prey (roe deer and larger), not giving the possibility to find most of the smaller prey (hare), at which the lynx does not stop longer. Small lynx prey were found only by chance and are certainly underestimated in the prey species composition.

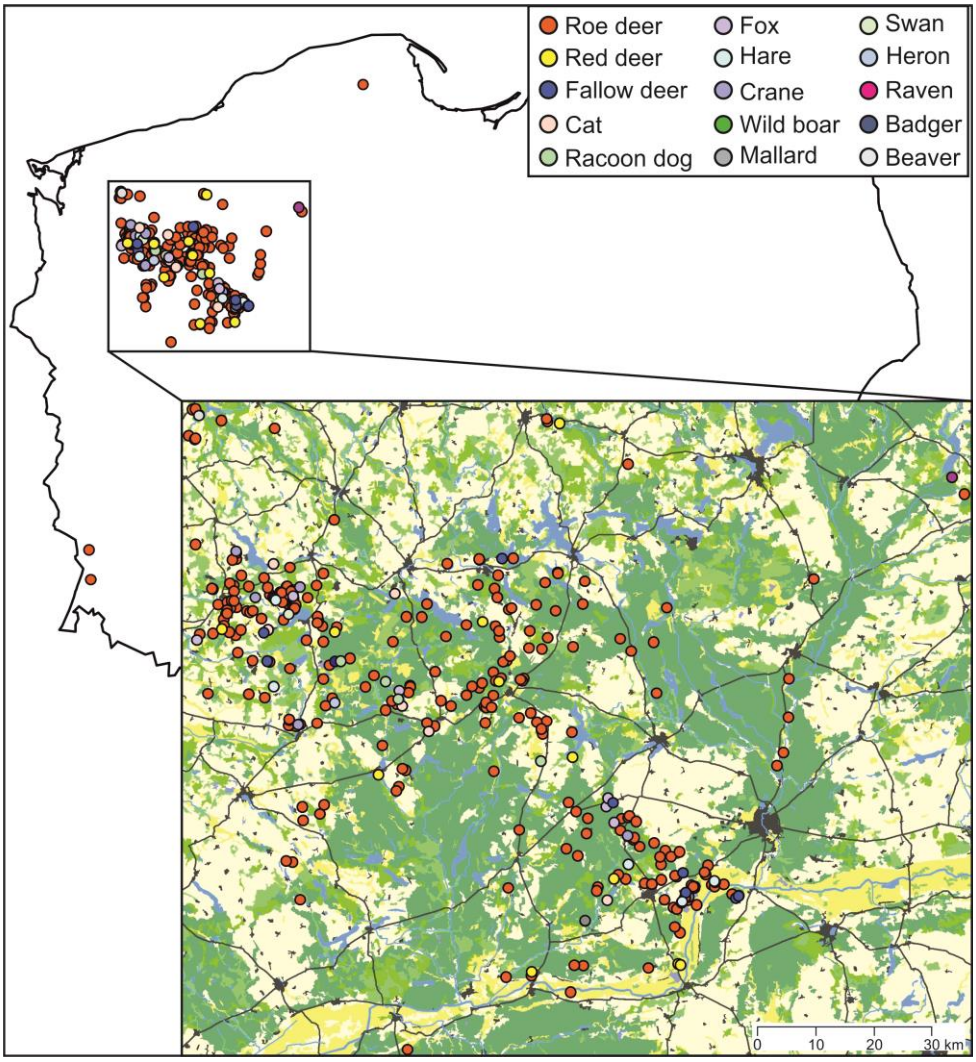

Fig. 23. Distribution of lynx prey.

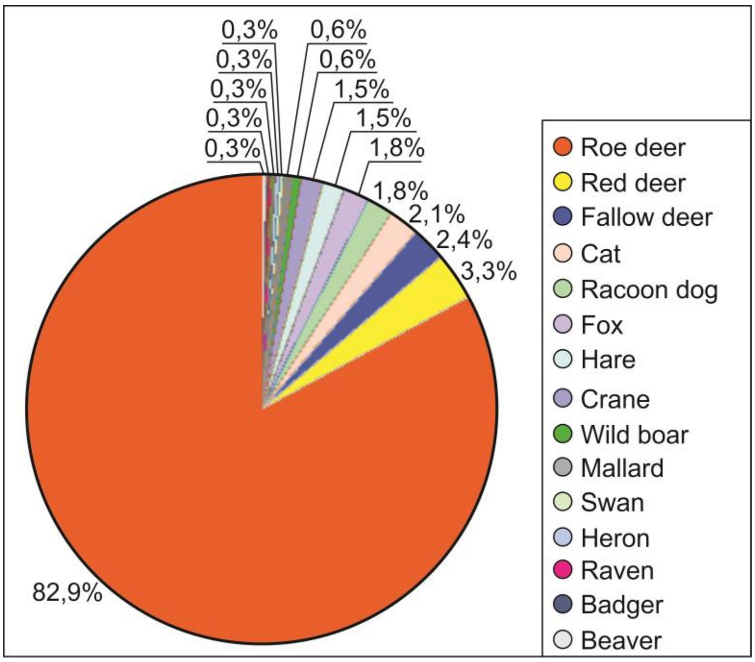

Fig. 24. Species composition of lynx prey.

10. Reproductive success of lynx

Only data from adult females (>1 year old) that were released before mating period were included in analyses of lynx reproductive success. Breeding (observation of kittens) was confirmed in 77% of possible cases (Fig. 24). In two females, reproduction was observed in two consecutive years, and it is worth noting that these were females released into the wild after five and nine years of captivity. In total, by 31.12.2021, the birth of 25 kittens was confirmed. The litter size ranged from 1 to 4 kittens (mean = 2.5 kittens per litter) (Fig. 25).

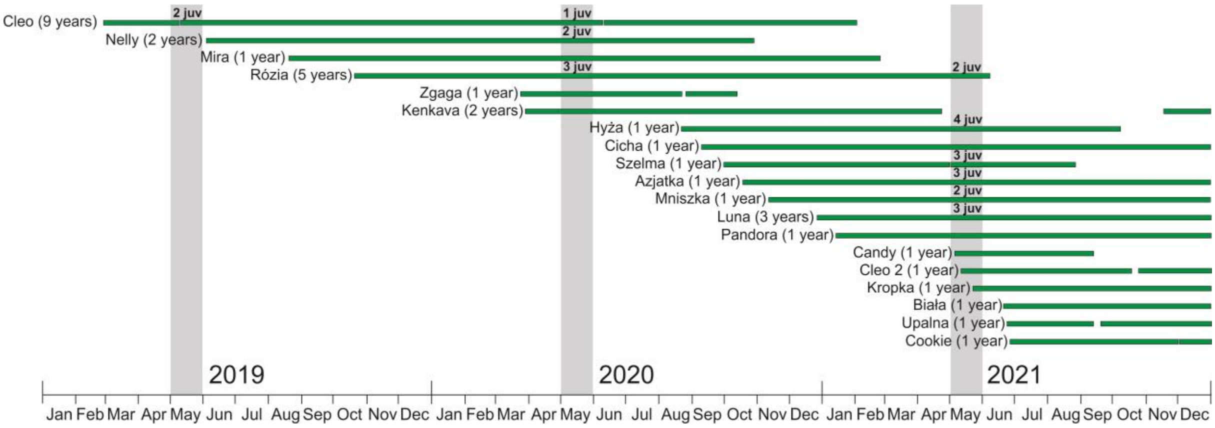

Fig. 25. Tracking period of adult female lynx reintroduced within a project during 2019-2021 with information on number of litters and litter size.

11. Lynx survival and risk factors

Based on the lynx GPS-tracking data and confirmed deaths of lynx, the survival of lynx was estimated for period from 1st to 1029th day (maximum tracking time) after release of lynx into the wild. The results indicated that mean lynx survival during the above-mentioned period was 62.7%, whereas in the first year after release it was 85.2% (Fig. 26). The lynx survival in the first year after lynx release was similar to that reported in natural (63%; Jędrzejewski et al. 1996) and reintroduced populations (adults – 76%, subadults – 53%; Breitenmoser-Würsten et al. 2007). The most common identified cause of death were traffic accidents and mange infection (27.8% and 22.2%, respectively). The remaining four lynx, for which the cause of dead was determined, died due to: gastroenteritis (5.6%), blockage of rectum (5.6%), heart attack(5.6%) and attack another predator (5.6%) In the remaining cases (27.8%) the cause of death was not determined.

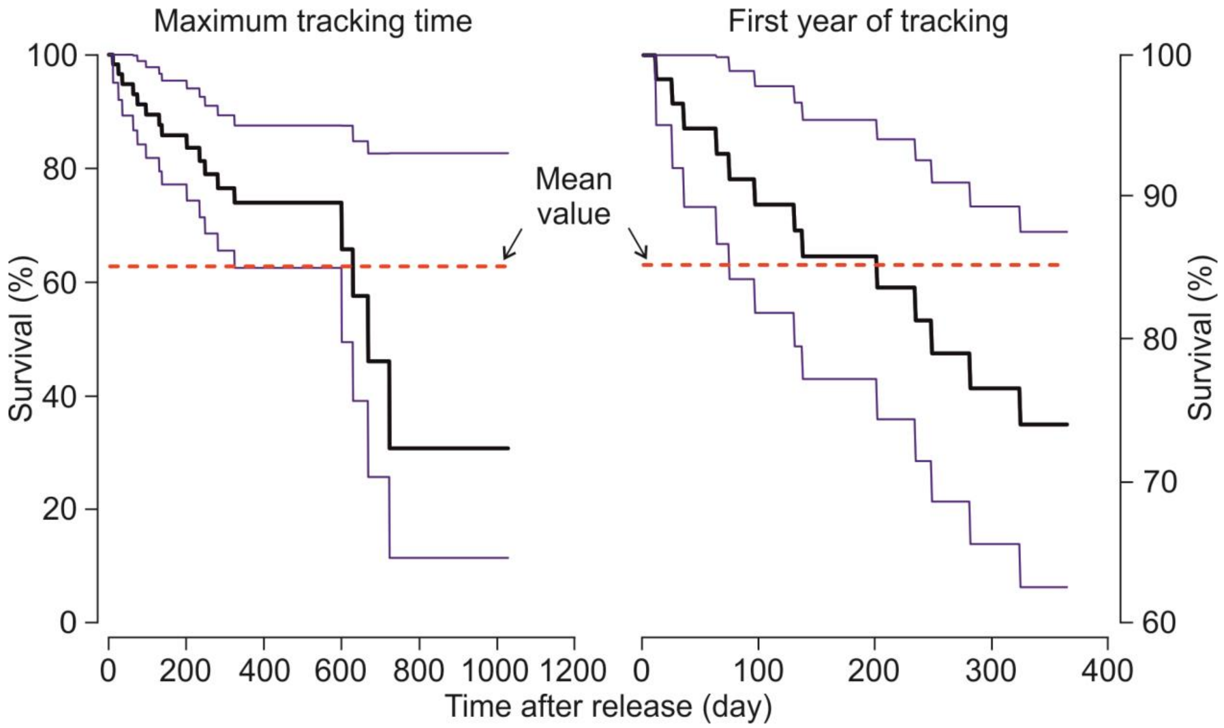

Fig. 26. Lynx survival in consecutive days after release into the wild.

II. GUIDELINES TO THE METHODOLOGY OF LYNX REINTRODUCTION

1) Analyses of data from the project „*The return of lynx to north-western Poland*"

a) Lynx origin, breeding, age and sex structure, adaptation

Between 2019 and 2021, 62 lynx (26 females and 36 males) were released into the wild within the project "The return of lynx to north-western Poland". The animals were obtained from 27 zoos and breeding centres in five different countries, i.e. Poland, Austria, Germany, Latvia and Estonia. The conditions in the centres varied from small cages of a few acres to large 4 ha enclosures. However, the size of the enclosure probably did not affect the animals' behaviour (reaction to the presence of humans), as lynx bred in large enclosures were often accustomed to approaching the fence at feeding times. Mean age of lynx at the time of their arrival at adaptation centre was 1.5 years. The youngest lynx were about 3.5 months old, but before their release they stayed in the adaptation pens for another 6 months, to reach the age when these carnivores begin their independent lives in natural conditions. The oldest individual stayed in captivity for almost 9 years (Table 2).

After being brought to the project area, lynx were kept in adaptation pens for 116 days on average, with the shortest adaptation period of 5 days and the longest of 1385 days. Predators stayed individually in enclosures of approximately 0.5 ha overgrown with natural vegetation (trees, bushes) facilitating shelter (Fig. 27). They were fed mainly on whole ungulate carcasses from road accidents (roe deer, fallow deer, red deer). The food was provided by 1-2 persons taking precautions to reduce human scent (e.g. rubber gloves). Human presence at the pens was kept to the necessary minimum, for feeding purposes only. The animals were under constant veterinary care.

Fig. 27. Enclosure system in Dłusko.

All (except three individuals that escaped from the enclosure) released lynx were equipped with telemetry collars to enable tracking of their movements and monitoring their adaptation to life in the wild (Fig. 28). During the analysed period from the start of the project until 31 December 2021, mean duration of lynx GPS-tracking was 11.6 months. Most animals (42 individuals) survived a minimum of 6 months, noting that this period is limited by the end date of the data collection covered by this report (some of animals are still observed in 2022). The longest life span and observation of lynx in the wild was over 34 months (Table 2).

Ryc. 28. Equipping lynx with GPS-collar befor releasing into the wild.

The length of recorded life span of lynx in the wild was weakly positively correlated with the time spent in captivity (before being brought to the adaptation centre) (R = 0.27, P = 0.04) and was not correlated with the length of the adaptation period (R = 0.07, P = 0.61) (Fig. 29). For example, the oldest female (Cleo), which had spent almost 9 years in captivity, after a short adaptation period of 9 days was one of the longest-lived individuals in the wild, where she survived for almost 2 years. This female gave birth to young twice in the wild and died, amongst other things, due to mange infection.

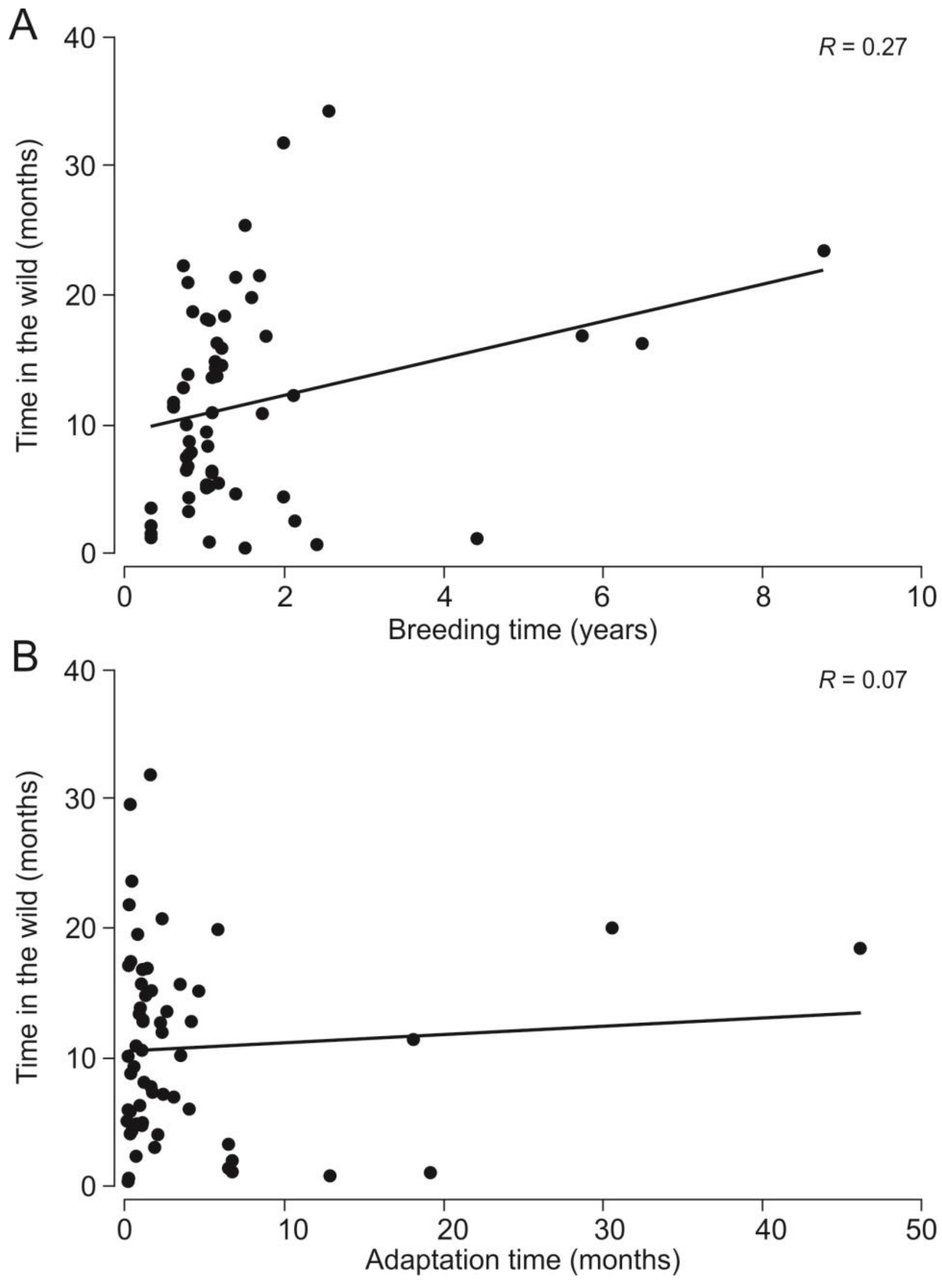

Fig. 29. Correlation between lynx life span in the wild and time spent in captivity (A) and adaptation time (B).

Number and age and sex structure of individuals

In the "The return of lynx to north-eastern Poland" project, the main emphasis was on initiating a population from as many founder individuals with proved pedigree and genotype as possible. This was to avoid the failures of previous lynx reintroduction programmes in Europe, which resulted in the establishment of populations with high levels of inbreeding (Mueller et al. 2022). In the project, 62 lynx were released including 26 females and 36 males (Table 2). The predominance of males among released lynx is, on the one hand, a result of the availability of animals in breeding centres, but on the other hand, this stem from the higher mortality of males (Premier et al. in preparation). Therefore, it was important to take into account the likely losses among males when establishing a new population in an area unoccupied by this species. Indeed, 63% (11 of 18 dead) of the lynx that died during the project were males.

Most of the released lynx were in their second (52.5%) or first (28.8%) year of life. Less numerous were individuals aged over two years old (13.6%) and under half year old (5.1%). As shown above, the age of the lynx (equivalent to the time spent in breeding), however, had small effect on the length of their life monitored after release. Among the individuals that survived the longest were also the oldest lynx, including a female that joined the project at almost 9 years of age. Also, the group of those individuals with the shortest life span (less than 6 months) consisted of both the youngest and several years old lynx.

b) Monitoring the functioning of lynx in the wild

Space use

After release into the wild, lynx moved over varying distances in search of a suitable area to settle. A few individuals moved outside reintroduction area, even up to distances exceeding 500 km. Some of these lynx were trapped and re-released within the reintroduction area. However, it should be noted that most of the released individuals used the areas assumed to be inhabited according to reintroduction programme (Fig. 30).

Fig. 30. Azjatka and Dawid in the wild.

Both the mobility of lynx and the size of their ranges increased with time after release, with both parameters stabilizing from about 12 months onwards. This may indicate that after one year, most of the released individuals found a suitable area to settle and establish stationary range.

Importantly, the spatial organization of home ranges of released lynx was similar to that observed in natural populations of the species. The sizes of individual ranges determined for the periods when lynx used the space in a sedentary way were similar to those recorded in the Białowieża Forest (Schmidt 2008). The largest individual home ranges of these predators were observed in northern Norway, where their size reached up to 4800 km^2 (Linnell et al. 2021). As in natural populations, males moved greater distances and used larger areas than females. Reintroduced individuals also exhibited seasonal variation in movements characteristic for wild lynx, showing the highest mobility during the mating period (males) and the lowest mobility during the period of rearing young (females). The similarity to natural populations was also noted for spatial distribution of individuals. The highest degree of overlap was observed for the home ranges of adjacent individuals of different sexes, while the lowest degree of overlap was observed in the case of females. Similar results were obtained both in natural lynx populations from the Białowieża Forest and Sweden (Schmidt et al. 1997, Mattison et al. 2011) as well as in the reintroduced population in Switzerland (Bretitenmoser-Würsten et al. 2007).

Food acquisition

The ability to prey independently and prey composition are important indicators of the success of reintroduction of large carnivores. Lynx released into the wild after the adaptation period, during which animals were fed on natural food (carcasses of wild animals), showed high hunting efficiency. The remains of 334 prey of 15 different animal species killed by 53 lynx were found. Among found prey, the main species was roe deer, whose share among all hunted animals was 83% (Fig. 31, Fig. 32). It is worth highlighting, that roe deer is the most common prey species of wild lynx living in natural populations in Europe (Jędrzejewski et al. 1993).

Fig. 31. Prey hunted by lynx in the wild. Note the species-specific traces of prey burrowing under available material (leaves, grass, prey hair).

Fig. 32. Lynx prey entirely hidden under the litter.

Only in the case of six lynx these predators killed human-bred animals (farmed fallow deer, chickens, goat). However, these were incidental events in life of each of these individuals, which resulted from their poor health (mange infection), or circumstances which favoured obtaining easy prey (poorly secured fallow deer farm). Importantly, after intervention (trapping, or treatment), lynx showed no further interest in livestock. These data prove the high adaptation of lynx born and raised in captivity to life in the wild without coming into conflicts with humans.

Mortality

Of the 62 lynx released into the wild, 18 were found dead. These lynx lived in the wild for 8 months on average. The female with the shortest life span (12 days) was killed by train. The maximum lifespan of lynx among those that died during the project implementation was over 23 months (Table 2). The most common identified cause of death were traffic accidents and mange infection (27.8% and 22.2%, respectively). The remaining four lynx, for which the cause of dead was determined, died due to: gastroenteritis (5.6%), blockage of rectum (5.6%), heart attack(5.6%) and attack another predator (5.6%) In the remaining cases (27.8%) the cause of death was not determined.

A remarkable achievement of the project was the successful treatment of lynx infected with mange. Two males (Rudy and Rumcajs) were affected during the reporting period (till31.12.2021) (Table 2). One of these predators was trapped due to a highly advanced infestation by these parasites after almost three years in the wild, while the other was trapped after about eight months of release. After a 2-4 month treatment and rehabilitation they were re-released into the wild (Fig. 33).

Fig. 33. Rudy recaptured due to mange infection.

It is worth mentioning another case of a female (including female Azjatka which was retrapped with 3 kittens) already after the reporting period (in 2022). All individuals showed signs of mange infection and after treatment were released to the wild (Table 2) (Fig. 34). A female Cleo retrapped and treated for mange infection could not be rescued (she died of a heart attack). The extremely emaciated, mange-infected female Hyża could not be rescued either. A total of 5 individuals have been treated and re-released and another individual is undergoing treatment (May 2022). These cases show a remarkable potential for effective intervention and treatment of animals even with highly advanced disease, which has a positive impact on the effectiveness of the reintroduction programme of this species.

Fig. 34. The release of Azjatka with daughters born in the wild after being treated for mange.

Reproduction

Ten successful reproductions by eight different females were recorded during implementation of the project (Fig. 35). In total, females in the wild gave birth to 25 kittens (Table 2). However, this number may be higher, as it is highly likely that not all births could be confirmed. Two lynx (Rózia and Cleo) gave birth twice in consecutive years. On average 2.5 kittens were born per litter. The maximum number was 4 kittens (this happens extremely rarely in the wild), and the least number was one kitten. Of the 25 kittens, 5 lynx had died by the end of the reporting period. One of them died due to mange infection, two others due to the loss of their mother and one female lost two kittens in the first month after birth due to unknown reasons. Six other kittens had already died in 2022 mainly (71%) due to mange infection. The reproduction of lynx in the newly established population is the most important indicator of the success of the reintroduction programme of this large predator. The first generation of kittens born in the wild will constitute an important part of the population, which should guarantee a sustainable effect of the project. These animals should be fully adapted to live independently in their environment and show natural behaviour including fear of humans.

Fig. 35. Kittens of reintroduced lynx born in the wild. On the left the offspring of Szelma born in 2021, on the right the offspring of Luna born in 2022.

Intervention trapping of lynx

Five lynx were recaptured and translocated to other locations (Table 2) (Fig. 36). Two males were translocated due to single incidents of their attacks on fallow deer in closed farms. Two females were retrapped because they appeared near human settlements, while in the case of one individual it was decided to relocate it because it wandered outside the reintroduction area. These five individuals did not cause any more problems after translocation. One lynx (male Piernik) was trapped and permanently placed in enclosure as it was not afraid of humans. Two other lynx, after recapture, could not be re-released to the wild because their health status (mange infection, neurological problems). It is worth highlighting that five individuals, including female with kittens, which were infected with mange recovered and they were released into the wild (Table 2).

Fig. 36. Retrapping of Azjatka infected with mange.

Environmental characteristics of the reintroduction areas

On the basis of the analyses described in Chapter 6 (Part I) it can be concluded that in the reintroduction area, lynx utilized environment consistent with their biology, i.e. they used forest areas, although with a clear tendency to stay close to the forest edge, characterized at the same time by relatively high roe deer densities. Given that roe deer prefer ecotone habitats (the edge of forest and open areas), this type of habitat use by lynx guarantees good conditions for hunting. The analysis also showed that lynx avoided anthropogenic landscape features such as buildings and roads, which indicates that the captive-raised animals quickly adapted to natural conditions (Fig. 37).

Fig. 37. Luna with kittens born in 2021.

However, within their individual home ranges, lynx mainly selected forest fragments that best fit to their biological requirements, characterised by a relatively short distance from the forest edge, low to medium tree cover (up to about 60-70%) and a high share of undergrowth. These characteristics indicate that the environment used by lynx must provide both accessibility to places preferred by their main prey – roe deer (the ecotone and mid-forest clearings) and vegetation cover (undergrowth) enabling close approach to prey, which is important for an ambush predator. However, it should be noted that the area of forest habitats that meets all these conditions to the highest degree (useful to a minimum of 50%) covered only 20.6% of the area used by stationary lynx (Fig. 20).

2) Analysis of methodology adopted in previous lynx reintroduction projects in Poland and other countries

So far, lynx reintroduction programmes in Europe have been based on three main methods:

1) translocations (trapping wild animals in existing wild populations and translocating them into the reintroduction area),

2) raising and reproduction of animals in order to release their offspring into the wild,

3) taking animals from breeding centres to release them to the wild.

A modification of method 2 is called „born to be free", which consists in gradual habituation of kittens being under the care of their mothers to life in the wild. Due to the special design of the cage, kittens can go outside freely until they reach the size that prevents them returning to the cage. In the case of translocations, two modifications called „soft release" and „hard release" are applied. The first method involves a period of quarantine and adaptation to the new environment, whereas in second method animals are released to the wild immediately after bringing them to the target reintroduction site. The fate of animals after release is usually monitored by telemetry (exception – programme in the Harz Mountains in Germany).

a) Lynx reintroduction programmes in Poland

Two lynx reintroduction programmes were carried out in Poland prior to the present project. The first one was carried out between 1993 and 2000 in the Kampinos Forest (Böer et al. 2000) and the second one in the Piska Forest between 2004 and 2018 (Jakimiuk 2015, personal communication).

1) The programme in the **Kampinos Forest** consisted in a method of obtaining animals from breeding centres and subjecting them to special „training" lasting from 10 to 453 days (average 192 days). A total of 31 lynx (14 males and 17 females) were released. Fourteen lynx died during the project mainly due to road accidents. The mean life span was 272 days (range 47 to 952 days). Five individuals were recaptured due to livestock depredation. Six females gave birth in the wild and raised 1-2 kittens. It was estimated that as a result of the project, 19 lynx (including 9 born in the wild) were present in the reintroduction area when the projected ended in 2000 (Böer et al. 2000).

2) In the **Piska Forest**, 31 lynx (16 males and 15 females) were released into the wild during implementation of the reintroduction programme. Twenty-five lynx were introduced with the „**born to be free**" (BTF) method, and 6 wild individuals were translocated from Estonia. Kittens born in the breeding cages located in the Piska Forest or in the breeding centre in Kadzidłowo, after which they were transported with their mothers to reintroduction enclosures. Kittens born within the BTF programme stayed with their mothers from 6 to 12 weeks, after which they started to leave a cage on their own. The lynx, which went outside to the natural habitats, stayed for a long time (even up to 12 months) in the forest near the cage, where the food was provided

for them. As time passed, subadult lynx living the wild were fed with decreasing frequency (Jakimiuk 2015). Since 2010, GPS-tracking of subadult lynx was carried out. Collars were put on individuals aged 10-11 months. However, not all individuals were caught and only part of subadults were fixed with transmitters. However, these lynx were tagged with chips, which provided information on six deaths, at least two of which resulted from traffic collisions. High mortality was recorded in juveniles up to 10 months of age (before putting on the telemetry collar). In 2016-2019, 5 out of 11 juveniles did not survive longer than 7 months. Of the six lynx **translocated** to the Piska Forest (3 males and 3 females) 5 were released by the „hard release" method, immediately after arrival, and one (subadult female) was kept in an 8-week quarantine. Two lynx were found dead (one in the same year and the other after three years of living in the wild). Reproduction was observed in a female translocated from Estonia, which had undergone a quarantine period prior to release.

The observed mortality of young lynx released using the BTF method may suggest that this method does not guarantee successful adaptation of young predators to independent life. However, as all individuals introduced with this method to environment were not equipped with GPS transmitters, it is difficult to assess the real mortality level. The lynx reintroduction programme in the Piska Forest lasted 14 years. An assessment of programme effectiveness conducted in 2015 indicated the occurrence of at least 10 lynx in the Masurian Lakeland (Jakimiuk 2015). The presence of the local lynx population in this region is also confirmed by the report on the project "Pilot monitoring of lynx and wolf in Poland in 2017-2020" conducted by the Main Inspectorate for Environmental Protection (GIOŚ). In the 2019/2020 season, the occurrence of lynx was found in the area of 1500 km2 of the Masurian Lakeland, including 500 km2 as the area of permanent occurrence of this species. Winter tracking and year-round observations carried out at the monitoring site in the Piska Forest in 2018 (the main forest complex of the Masurian Lakeland) showed 10 findings of individuals, including a female with two kittens (Śmietana et al. 2020).

Nevertheless, monitoring carried out in 2021 in the Piska Forest using hair traps and genetic studies confirmed the presence of only 4 individuals (exclusively males) (Ratkiewicz et al. 2021). It seems that the relatively low density and poor reproduction of lynx in this area may result mainly from significant extension of the reintroduction process in time – an average of two lynx were released into the wild annually. An important limitation was also the lack of GPS-tracking data for the part of released lynx, so there is no data to fully assess the effectiveness of the programme.

b) Other lynx reintroduction programmes in Europe

Of the lynx reintroduction programmes in Europe, comparative data were available from Germany (Harz Mountains), Switzerland (Alps) and Slovenia/Croatia (Julian Alps and Dinaric Mountains).

1) The aim of the lynx reintroduction programme in the **Harz Mountains** was to establish a new population in an area where lynx did not occur more than 300 km away from the nearest lynx population in the Bavarian Forest. The project was carried out between 2000 and 2006 and during this period 24 individuals (15 females and 9 males) were released (Anders and Middelhoff 2021). Mainly subadult lynx were released (1-2 years), but some reintroduced lynx were animals over 3 years old (O. Anders pers. com.). All individuals came from zoos and wildlife parks, similar to the "The return of lynx to north-western Poland" project, but they were not equipped with the GPS collars. Before release, lynx were initially kept for acclimatization for about 7 days in 100 m^2 cages, and then translocated to a larger 4-ha enclosure for an adaptation period (several weeks), during which they were accustomed to eating meat of wild ungulates (roe deer, red deer). Of the eight lynx found dead after release, most died due to mange infection (4 individuals), and the others died in traffic collisions or for unknown causes (Anders and Sacher 2005). In the wild lynx survived from 2 to 44 months (mean = 18.2 months). Two lynx were recaptured due to lack of fear of humans (Anders 2016).

   Despite the relatively small size of the founder population released over 6 years, the lynx reintroduction programme in the Harz Mountains was very successful. Nowadays, the lynx population size in this area is estimated to be 55 lynx (2.5 individuals/100 km^2) (Anders and Middelhoff 2021). At the same time, an expansion of individuals from this population to other areas has been observed (even over 300 km). More importantly, this population among the genetically tested reintroduced lynx populations in Europe expresses the highest heterozygosity and the lowest inbreeding coefficient, comparable to the natural populations in Poland and Latvia (Mueller et al. 2022). This is probably due to the fact that lynx came from different genetic lineages represented in many breeding centres in Germany and Sweden, resulting in the inclusion of diverse alleles in the population. However, it should be mentioned that, despite this, a decrease in heterozygosity is observed there with time (Mueller et al. 2020).

2) As in the Harz Mountains, the **LUNO project** conducted **in the Eastern Swiss Alps** aimed at establishing a new lynx population. Unlike the German project, however, this programme used the method of translocation of wild animals (from the Western Alps and the Jura Mountains) and, in addition, all released lynx were equipped with telemetry collars. The project was conducted between 2001 and 2003, but lynx were only released in two seasons, i.e. in 2001 (6 individuals) and 2003 (3 individuals) (Ryser et al. 2004). A total of 4 males and 5 females were reintroduced. After capture from the wild, lynx were quarantined for 1 to 4 weeks and then released into the wild. Two males died, with one of them after more than two years due to a heart defect and the other after only about 5 months after release from unknown causes. The transmitters of two other lynx stopped working after 11 and 20 months. Reproduction was confirmed for only two females, but intensive monitoring was carried out only until 2003. For several years after the lynx translocation, it was thought that the effects of the project did not live up expectation due to the lack of confirmed reproduction of most females, the death of two males and the settlement of a third male away from the released females. However, monitoring carried out in 2012 showed that there are still about 10 lynx in the reintroduction area, including two females with kittens (Ryser et al. 2012). One of the problems encountered during this reintroduction programme using lynx trapped in the wild was that all individuals, with the exception of one female, undertook more or less long-distance movements before establishing stationary home ranges (Ryser et al. 2004). The most spectacular example was the male Turo, which, after a multi-kilometre movement, during which it had to be recaptured, settled for several months in the urban agglomeration of Zurich.

3) The lynx reintroduction project conducted simultaneously in two countries, Croatia and Slovenia, has been carried out since 2019 in the **Dinaric Mountains** and the **Julian Alps**. The project aims to strengthen the existing lynx population due to their low abundance, low genetic variability and very high level of inbreeding (Fležar et al. 2022). Reintroduction is carried out through translocations of wild lynx from the

Carpathian populations in Slovakia and Romania, and the fate of the animals is monitored with telemetry. By the end of 2021, a total of 13 lynx (10 males and 3 females) were translocated, 5 individuals in the Dinaric Mountains and the remaining 8 (including all females) in the Alps (https://www.lifelynx.eu). After capture, the animals were kept in captivity (before translocation and release) an average of 110 days (ranging from 40 to 570 days). After being brought to the reintroduction site, they were released immediately into the wild (in Croatia) or after an adaptation period of 4 to 48 days (in Slovenia). The observed life span of lynx after their release ranges from 7 to 32 months. Most lynx, before establishing stationary home ranges, took long-distance movements (even over 100 km in a straight line), crossing the border between Croatia and Slovenia several times (Krofel et al. 2020). Two individuals most probably died, including one after 9 months of tracking, and the other disappeared immediately after release, but their carcasses have not been found. The fate of the third lynx is also unknown. Of the tree translocated females, one was already pregnant and probably gave birth in the wild, whereas the other became pregnant in the wild and gave birth to 3 kittens.

The programme is on-going, thus it is difficult to assess its long-term effects. However, preliminary simulations have shown that the inbreeding coefficient in the population should be significantly reduced if all released individuals participate in breeding (Fležar et al. 2022). As the project did not aim at creating a new population but improving the genetic diversity of the existing population, its implementation using a relatively small number of individuals may prove successful.

c) Critical evaluation of the different solutions

The above-described examples of lynx reintroduction programmes show that, regardless of the methods applied, these procedures are subject to certain risks, which must be foreseen and included in the action plan (animal losses, problems of adaptation to the new location, dispersion outside the target reintroduction site, reproduction problems). Nevertheless, it should be emphasized that each methodological approach produced, at least partially, the expected results. Acquisition of animals both from breeding centres and from the wild populations was an effective solution. Most of the lynx adapted to the new environment, the successful reproduction in the wild was confirmed, resulting in stabilization and even expansion of the population to other areas.

The significant advantages of releasing lynx from zoos and breeding centres are the possibility of obtaining a large number of individuals in a relatively short time and effective control of their health and genetics. A very serious problem of the lynx reintroduction programmes in Europe carried out so far has been the establishing of populations from a small number of founder individuals, which in the majority of populations led to a high level of inbreeding compared to indigenous populations (Mueller et al. 2022). It is worth mentioning that this mainly concerns projects in which free-ranging animals were obtained for resettlement. Obtaining animals from captivity allows not only diversification of their genetic background, but also preliminary examination of genotypes of available individuals in order to select or not recommend them for reintroduction. In this way, many individuals with different genotypes can be released into the wild in a short time, significantly increasing the genetic diversity of the future population and its chance of survival.

Obtaining animals from wild population is limited due to: (1) procedural reasons (CITES species), (2) the relatively low population densities and associated problems in trapping sufficient number of individuals for translocation, (3) the weakening of local populations, (4) the high stress on wild animals because of trapping, long-distance translocations and introduction into an unfamiliar environment, (5) long-distance movements of released animals, undertaken presumably to return to the previously inhabited area.

The capture of wild lynx for introduction is also disadvantageous due to the fact that the wild population of these animals usually consists of three age-sex groups: territorial adult males, adult females rearing their young, and a small number of subadult individuals (1-2 years old) without territories. Adult males, due to their stronger tendency to disperse than females (Schmidt 1998, Samelius et al. 2012), may, after translocation to a reintroduction site, more often undertake long-distance movements to return to the site from which they were caught. Consequently, they may contribute little to the project. Adult females, on the other hand, raise their young or are pregnant for most of the year. This means that the capture of such an individual for translocation may pose a very high risk to the survival of the offspring. As a result, from the wild-living lynx population, only subadults in the period of getting independence may be suitable candidates for a reintroduction project. For subadults there is a lower risk that they will leave the project area and at the same time their capture poses the least risk to the native population. However, wild predator trapping methods are usually not selective enough to ensure that lynx are captured at the required age.

At present, there are practically no populations of lowland lynx from which it would be possible to obtain larger numbers of individuals for reintroduction projects without endangering population stability. Acquiring animals from the wild is, moreover, difficult, time-consuming and therefore very expensive. In addition, given that for resettlement subadult individuals should be used, basing the project on animals from the wild would result in too low an overall number of animals participating in the project.

Animals obtained from the wild can be a very valuable addition to the founding group of the reintroduced lynx population, positively influencing its genetic diversity. It is particularly important to use specimens that were brought into captivity as a result of random events (e.g. orphaned kittens). In this way, individuals which would have had a low chance of survival without human intervention may be given a "second chance" and at the same time contribute to enriching the genetic pool of the created population.

An unfavourable trait of large carnivore reintroduction programmes is the risk of individuals occasionally appearing in urban areas, either because of the lack of fear of humans or for other reasons. Such situations, however, occur both in the case of lynx obtained from breeding centres and from the wild. A very important action adopted in most programmes was the use of telemetry, which allowed not only to monitor the fate of individual lynx but also to intervene in case of emergencies (problems with adaptation, conflicts, diseases).

The most unfavourable solution applied in lynx reintroduction programmes, according to genetic studies (Mueller et al. 2022), has been the use of an insufficient number of founders and the considerable extension of procedure over time. In particular, very few individuals (mainly from a single breeding centre) were successfully released in a project conducted in the Piska Forest for 14 years, resulting in relatively low reintroduction success. In comparison, the lynx reintroduction programme in the Harz Mountains conducted over a period more than twice as short (with twice as many lynx released per time unit coming from different genetic lineages, *nota bene*, originating from captivity) achieved a rapid effect in the form of a well-developing, expansive population. At the same time, this population in comparison with other reintroduced lynx populations expresses the highest genetic diversity. On the other hand, even here a decrease in heterozygosity over time has been observed recently (Mueller et al. 2020). Therefore, this example evidences that the initial success of reintroduction may be insufficient in the long term to guarantee sufficiently high genetic diversity and the sustainability of the population. In the Harz Mountains an additional negative role was played by complete isolation of reintroduced population, preventing immigration of individuals from neighbouring populations. This highlights that important factor besides the initial abundance and diversity of founder genetic lineages is also to ensure connectivity between neighbouring populations.

Based on the available data, it appears that using lynx from breeding centres and from the wild may provide comparable results provided that rigour is maintained in terms of numbers and diversity of individuals and breeding procedures. However, the 'born to be free' method for lynx seems to have a higher risk of failure due to the relatively early independence of the kittens (no direct care by the female) and the consequent need to feed them while they are outside the cage during the period of independence.

The project "The return of lynx to north-western Poland" used lynx from a number of breeding centres, which made it possible to obtain a large number of individuals, especially young ones, in a short period of time. This was an alternative solution to translocating wild animals and breeding lynx for reproduction and releasing their offspring. Both alternatives are characterised by low efficiency in obtaining large numbers of animals ready for reintroduction and by the considerable prolongation of procedures. The release of a large number of lynx originating from captivity allowed to saturate the reintroduction area, create opportunities and monitor the process of reproduction and the creation of spatial organization as well as social relations in the new population. The provision of almost all lynx with telemetric collars made it possible to follow the status of the lynx including their movements, survival, settlement in the environment, possibilities of obtaining food and reproduction.

3) Guidelines of best practices for selection, breeding and spatio-temporal procedures of animal release in lynx reintroduction programmes

a) Preparing the formal bases of the reintroduction programme

Before starting the activities related to the application of funds for the reintroduction programme, the purpose and substantive scope of the programme should be agreed with the relevant administrative and scientific institutions as well as land managers. Consideration should be given to the possibility of animal dispersal outside the planned reintroduction area, and taking into account the conditions and legal regulations in areas adjacent to the reintroduction area.

b) Selection of reintroduction area

Lynx is a species with high spatial requirements and it is sensitive to habitat fragmentation. Evaluation of the environment in terms of fragmentation and structure, allowing for the fulfilment of basic life requirements (obtaining food, hiding, reproduction), and food availability is essential for the selection of a suitable site for release of lynx.

c) The origin of reintroduced lynx

According to the IUCN recommendations, in species reintroduction programmes, population founders can be both wild and captive individuals (IUCN / SSC 2013). The results of the previous above-described actions, obtained both in this project and in other lynx reintroduction programmes conducted in other areas, confirm that in the case of this species both sources can be considered as equally suitable and used interchangeably or simultaneously.

At the stage of planning of the reintroduction programme, it is necessary to analyse the possibilities of obtaining a sufficient number of lynx (e.g. availability of animals in breeding centres), maintaining the appropriate sex ratio, as well as preliminary information on the origin of individuals. It should be kept in mind that the acquisition of a large number of lynx in a short period from the wild populations is not only logistically difficult, but may also threaten local populations of these cats. When creating a new population, in an area where lynx do not occur, reintroduction based only on wild lynx may prove ineffective. Instead, it is worth considering the use of animals from two sources.

d) The number and selection of individuals with regard to their genetics

The effectiveness of lynx reintroduction and the sustainability of the established population depends mainly on the simultaneous fulfilment of two basic conditions simultaneously: the release of a large number of founders in a relatively short period and ensuring (through genetic testing of imported lynx) that individuals are not related to each other and come from different genetic lineages. It is not possible to arbitrarily determine how many individuals should be introduced into the environment, as this depends on the aim of the project (to establish a new population or to strengthen an existing one), as well as on the size of the target reintroduction area, but also on the degree of isolation of a given area from the nearest lynx populations. In addition, when planning the number of animals, the mortality, which can reach over 30% of the released lynx, should be taken into account.

Considering above-mentioned examples of reintroduction projects of these predators, the number of released animals was highly variable and ranged from 2 to 20 per year on average. The lowest success was observed in projects with the lowest frequency of lynx release (2-3 individuals per year in projects in the Piska Forest and the Swiss Alps). Projects with an average release of at least 4 lynx per year led to the establishment of a well-developing populations (especially in the Harz Mountains), but from a population genetics point of view this abundance turns out to be insufficient (see above and: Mueller et al. 2020, 2022). Much higher number of individuals released into the wild in the present project (20 animals per year on average) takes into account both potential mortality and the conscious shaping of the genetic diversity and degree of inbreeding of the future population. In general, the sex ratio of the founder group should be close to 1:1, but a certain predominance of males may compensate for possible losses due to their higher mortality.

An important element of the reintroduction programme is genetic monitoring of individuals. In the case of animals obtained from breeding centres, before transporting them to adaptation enclosures, blood or hair samples should be taken in order to determine their assignment to a genetic lineages and degree of kinship. This information will help avoid the introduction of animals from genetically and geographically too distant populations and the crossing of closely related individuals.

If reintroduction is planned based on wild lynx from the Carpathian population, special attention should be paid to the need to select individuals from different parts of its range to ensure the greatest possible diversity of the founder group, given the high level of inbreeding found in this population (Mueller et al. 2022).

e) The process of releasing lynx into the wild

Veterinary care should be provided to animals in quarantine. During the adaptation period, observations of lynx behaviour (reaction to humans) should be carried out to exclude animals that do not afraid of humans. Predators should be fed with animal species which constitute their natural prey.

Different lynx should be introduced to the environment taking into account social interactions. Due to the possibility of intra-species aggression in lynx (Mattisson et al. 2013), release sites for single-sex individuals should be distant from each other according to the biology of the species. In lowlands this distance should be around 10 km (Linnell et al. 2007). The release of subsequent individuals should be preceded with analysis of telemetry data indicating the distribution of areas occupied by lynx released earlier.

f) Monitoring of the released lynx

Equipping animals with telemetry transmitters is an important task not only for ongoing monitoring of the implementation and effectiveness of reintroduction, but also for possible interventions in case of failure (Fig. 38). In this regard, the project team should ensure the possibility to collect and analyse location data from released lynx and conduct field inspections (e.g. to check hunting and breeding success).

Fig. 38. Telemetry collar replacement.

g) Monitoring of population development after completion of the reintroduction programme

Once the lynx reintroduction programme is completed, regular, multiannual activities should be planned to assess the sustainability of the effects of the programme. For this purpose available methods such as snow-tracking, photo-traps and hair traps to collect samples for genetic studies can be used.

CONCLUSIONS:

The long-term success of lynx reintroduction projects depends above all on the number and genetic variability of released individuals. This is because, the majority of lynx populations established as a result of reintroduction show high inbreeding rates. The analyses of individual reintroduction projects show that the sustainable success of population restoration depends on the following solutions:

1. **Using large numbers of individuals for reintroduction in a short period of time, which can be achieved by using captive born individuals. As shown by the results of previous projects, translocations of lynx from wild populations do not ensure adequate genetic diversity, reproductive success and do not guarantee adequate behaviour of lynx in the new area, probably due to the limited number of individuals obtained this way. The advantage of using animals from zoos and breeding centres is that large numbers of animals can be obtained in a relatively short time and their health and genetic status can be effectively controlled. Releasing animals from breeding centres makes it possible not only to diversify the genetic lineages from which they originate, but also to asses in advance the genotypes of available individuals for their suitability for reintroduction. In this way, a large number of individuals with area-specific genetic diversity can be released into the environment in a short period of time, significantly increasing the genetic diversity of the future population and therefore chances of survival.**

   According to IUCN recommendations, in species reintroduction programmes, population founders can be both wild and captive individuals (IUCN/SSC 2013). Obtaining large numbers of lynx from the wild in a short period of time is not only logistically difficult, but can also threaten local lynx populations, so reintroductions based mainly on captive individuals seem to have higher chance of success.

2. **Telemetric monitoring of all animals released into the wild allows to increase the effectiveness of the reintroduction programme. It should also be continued with regard to the generation of lynxes born in the wild, thanks to which it is possible to assess the effectiveness of the conducted actions and their constant modification. Telemetric monitoring, thanks to current data on the location of lynxes, also partly protects animals against poaching. Thanks to the constant**

update of data on the location of lynxes, it is possible to constantly monitor the state of their population and conduct effective interventions, such as treatment or, in the case of high mortality, release of subsequent lynxes into the wild.

3. **Reintroduction projects should have a long-term character in which the intensive initial period related to adaptation and release of lynx into the wild should be followed by a period of intensive telemetric monitoring of wild-born lynx and a continuous enrichment of the genetic pool of the population through the release of genetically particularly valuable individuals born in captivity or obtained from the wild. Such actions will prevent inbreeding increase in the newly established population until natural connectivity with other lynx populations is restored.**
4. **An important task of each reintroduction project should be systematic building of acceptance for the species among local communities in the reintroduction area. It is advisable to intervene in case of individuals exhibiting undesirable behaviour, to help protect domestic animals against attacks of this predator and to assist in inspection of traffic accident sites involving lynx. High social acceptance is an important factor improving population stability and survival.**

Table 2. Summary information on lynx individuals released in the reintroduction programme in 2019 - 2021. * - lynx which were captured and translocated.

No	**Name**	**Sex**	**Birth year**	**Arrival date**	**Time in the breeding centre** (years)	**Date of release**	**Adaptation time** (days)	**Time in the wild** (months)	**Reproduction** Year: number of kittens	**Status**
1	Piernik	M	2019	21.05.2020	1.0	25.06.2020	34	5.30		Recaptured 01.12.2020. Stays in a pen.
2	Rudy	M	2016	04.12.2018	2.6	23.01.2019	49	34.30		Recaptured due to the mange infection 17.11.2021. Treated at a rehabilitation centre. Released into the wild 02.2022.
3	Jurgen	M	2012	09.11.2018	6.5	29.03.2019	140	16.27		Lost contact 29.07.2020.
4	Pako	M	2018	05.02.2019	0.7	16.04.2019	71	12.83		Lost contact 05.05.2020.
5	Simba	M	2018	20.03.2019	0.8	02.04.2019	12	18.73		Lost contact 15.10.2020.
6	Dawid	M	2018	02.07.2019	1.1	30.07.2019	28	14.37		Lost contact 03.10.2020.
7	Jurek	M	2018	02.07.2019	1.1	07.08.2019	35	13.73		Lost contact 22.09.2020.
8	Mira	F	2018	13.08.2019	1.2	21.08.2019	8	18.40		Lost contact 23.02.2021.
9	Cień	M	2019	30.06.2020	1.1	30.07.2020	30	14.87		Lost contact 19.10.2021.
10	Rózia	F	2014	15.12.2015	1.6	20.10.2019	1385	19.83	2020: 3 2021: 2	Lost contact 06.06.2021.
11	Cysorz	M	2015	19.01.2017	1.7	07.08.2019	918	21.53		Lost contact 14.05.2021.
12	Hyża	F	2019	16.06.2020	1.1	24.08.2020	68	13.63	2021: 4	Lost contact 07.10.2021.
13	Szelma	F	2019	16.06.2020	1.1	02.10.2020	106	10.90	2021: 3	Lost contact 25.08.2021.
14	Zygmuś	M	2019	26.02.2020	0.8	31.03.2020	35	13.87		Lost contact 21.05.2021.
15	Ciocio	M	2014	07.02.2020	5.7	09.03.2020	32	16.87		Lost contact 28.07.2021 (broken collar).
16	Nagan	M	2017	10.05.2019	2.0	21.05.2019	11	31.83		In the field
17	Kenkava	F	2018	03.10.2019	1.4	29.03.2020	176	21.40		In the field

18	Rumcajs	M	2019	21.05.2020	1.0	04.07.2020	43	18.17		Recaptured due to the mange infection 11.03.2021 r. Treated at a rehabilitation centre. Released into the wild 02.07.2021.
19	Fidek	M	2019	03.06.2020	1.1	07.07.2020	34	18.07		In the field
20	Żebro	M	2019	08.07.2020	1.2	29.08.2020	51	16.30		In the field
21	Cicha	F	2019	30.07.2020	1.2	10.09.2020	40	15.90		In the field
22	Azjatka	F	2019	30.07.2020	1.2	20.10.2020	80	14.57	2021: 3	Captured with kittens due to mange infection 22.02.2022. All lynx treated in the rehabilitation centre. Released 07.04.2022. The third kitten was recaptured after the reporting period.
23	Mniszka	F	2019	08.07.2020	1.2	14.11.2020	126	13.73	2021: 2	In the field
24	Luna	F	2017	25.06.2019	2.1	29.12.2020	544	12.23	2021: 3	In the field
25	Pandora	F	2020	22.12.2020	0.6	14.01.2021	22	11.70		In the field
26	Widok	M	2020	22.12.2020	0.6	25.01.2021	33	11.33		In the field
27	C-360*	M	2020	19.02.2021	0.8	07.03.2021	18	9.97		In the field
28	Cleo2*	F	2020	02.03.2021	0.8	15.05.2021	73	7.67		In the field
29	Kropka	F	2020	19.02.2021	0.8	22.05.2021	93	7.43		In the field
30	Biała	F	2020	19.02.2021	0.8	21.06.2021	122	6.43		In the field
31	Upalna*	F	2020	16.06.2021	1.1	23.06.2021	7	6.37		In the field
32	Cookie*	F	2020	16.06.2021	1.1	27.06.2021	11	6.23		In the field
33	Atak	M	2020	16.07.2021	1.2	21.07.2021	5	5.43		In the field
34	Cezar*	M	2018	15.11.2019	1.5	29.11.2019	14	25.43		Lost contact 11.11.2021 (broken collar).
35	Złodziej	M	2018	01.03.2019	0.8	28.04.2019	57	3.23		Dead. Traffic accident. 03.08.2019
36	Łapa	M	2017	10.05.2019	2.0	21.05.2019	11	4.37		Dead. The cause of death was a blockage of rectum, 29.09.2019
37	Olza/Osa	M	2017	02.02.2019	1.7	09.02.2019	7	10.83		Dead. Mange infection. 31.12.2019

38	Łopuch	M	2018	22.05.2019	1.0	04.06.2019	12	9.40		Dead. Killed by other predator. 12.03.2020
39	Momo	M	2018	03.10.2019	1.4	17.10.2019	14	4.60		Dead. Traffic accident. 03.03.2020
40	Johnny	M	2018	28.05.2019	1.0	18.07.2019	50	8.30		Dead. Mange infection. 31.12.2019
41	Zgaga	F	2019	26.02.2020	0.8	25.03.2020	29	6.73		Dead. Traffic accident. 13.10.2020
42	Ucho	M	2018	30.06.2020	2.1	22.07.2020	22	2.50		Dead. Cause unknown. 05.10.2020
43	Nelly	F	2017	19.02.2019	1.8	04.06.2019	105	16.83	2020: 2	Dead. Cause: Gastroenteritis. 21.10.2020
44	Wirus	M	2019	12.03.2020	0.8	05.05.2020	53	7.83		Dead. Mange infection. 26.12.2020
45	Speedy	M	2018	05.02.2019	0.7	16.04.2019	71	22.30		Dead. Mange infection. 13.02.2021
46	Cleo	F	2010	19.02.2019	8.8	28.02.2019	9	23.47	2019: 2 2020: 1	Dead. Mange infection. Treated at a rehabilitation centre. 1.02. - 11.03.2021. Died of a heart attack.
47	Zenek	M	2019	26.02.2020	0.8	21.03.2020	25	21.00		Dead. Traffic accident. 11.12.2021
48	Bałagan	M	2019	03.03.2020	0.8	10.04.2020	37	8.67		Lost contact 26.12.2020 r.
49	Piekło	M	2019	21.05.2020	1.0	24.06.2020	33	5.07		Lost contact 23.11.2020 r.
50	Grzybiarz	M	2019	03.06.2020	1.1	26.06.2020	23	5.20		Lost contact 29.11.2020 r.
51	Candy	F	2020	02.03.2021	0.8	05.05.2021	63	4.30		Lost contact 11.09.2021 r.
52	Duszenka	F	2013	13.10.2017	4.4	19.05.2019	576	1.13		Dead. Cause unknown. 22.06.2019 (cut collar)
53	Ryszard	M	2019	10.09.2019	0.3	26.03.2020	196	3.50		Recapture due to traffic accident 09.07.2020. Stays at the rehabilitation centre in Stobnica.
54	Kończak	M	2019	10.09.2019	0.3	26.03.2020	196	1.50		Lost contact 10.05.2020 r.
55	Bazyl	M	2019	10.09.2019	0.3	03.04.2020	203	2.13		Dead. Cause unknown.

										06.06.2020
56	Papiernia	F	2019	10.09.2019	0.3	03.04.2020	203	1.20		Dead. Cause unknown. 09.05.2020
57	Mamut	M	2017	10.10.2019	2.4	18.10.2019	8	0.67		Lost contact. 07.11.2019 r.
58	Kleopatra	F	2018	15.11.2019	1.5	22.11.2019	7	0.40		Dead. Traffic accident. 04.12.2019
59	Demokracja	F	2019	03.06.2020	1.1	30.06.2021	387	0.87		Dead. Cause unknown. 26.07.2021.
60	Gretta	F	2016	13.10.2017	1.4	04.09.2019	681	-		Escaped from the pen without telemetry collar.
61	Kredka	F	2019	-	-	04.09.2019	-	-		Escaped from the pen without telemetry collar.
62	Wąsatka	F	2020	-	-	04.03.2021	-	-		Escaped from the pen without telemetry collar.

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