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RESEARCH PAPER

Early post-release behaviour of Eurasian lynx translocated to the transboundary region of the Dinaric Mountains

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Abstract. Translocations of individuals for re-introductions and population reinforcements have been increasingly used in carnivore conservation. Movement is the first behavioural response of reintroduced animals to "forced dispersal" in a new habitat. Our study investigated space use and movement patterns of six male Eurasian lynx (*Lynx lynx*) translocated from the Carpathian to the Dinaric Mountains and released at four different sites in Croatia and Slovenia. Data were collected during their early post-release period (i.e. three months after the release) to investigate the first behavioural response following the translocation. Released lynx were monitored with GPS-GSM-VHF telemetry collars set to collect GPS locations in intervals between 4 and 24 h. All animals settled during the study period, on average 23 days (SD = 16.5) after the release. Although outside of the monitoring period that was the focus of this study, two lynx left their first territory 102 and 92 days after their release and went on a second exploratory movement. The main movement direction of the released animals was to the NW-SE, corresponding to the orientation of the predominant ridgelines of the Dinaric Mountain range. Furthermore, by comparing the use and availability of the terrain aspect, we concluded that the lynx chose to move along the mountain range and not perpendicular to the mountain, i.e. they avoided moving uphill and downhill. First kill sites of all animals were detected on average 3.4 days (SD = 1.7) after the release. This study brought valuable theoretical and practical knowledge on the early movement behaviour of translocated lynx that should be considered when planning translocations.

Key words: *Lynx lynx*, reinforcement, exploratory movement, post-release monitoring

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Introduction

Translocations of individuals for re-introductions and population reinforcement have been increasingly used in carnivore conservation (Breitenmoser et al. 1998, Cop & Frkovic 1998, Vandel et al. 2006, Rueda et al. 2021). However, such efforts can be extremely costly, risky, and fraught with political and social challenges (Breitenmoser et al. 1998, Fischer & Lindenmeyer 2000, Devineau et al. 2010). Nevertheless, several key publications that conducted extensive surveys and reviews of re-introduction efforts present important findings regarding the factors that affect success rates and offer relevant guidance for future translocation efforts (Miller et al. 1999, Fischer & Lindenmayer 2000, Linnell et al. 2009, Pérez et al. 2012, Rueda et al. 2021). Others demonstrate that little information exists about past translocation efforts, nor have these cases been well studied, while unsuccessful translocations are generally not reported or underreported (Miller et al. 1999, Linnell et al. 2009).

Movement is the first behavioural response of translocated animals to "forced dispersal" in a new habitat (Stamps & Swaisgood 2007). Thus, movement patterns in the early post-release period are critical for the survival and establishment of reintroduced animals (Preatoni et al. 2005, Berger-Tal & Saltz 2014). However, information available on the early post-release movement of translocated carnivores remains limited for most species primarily due to the lack of published data on telemetry monitoring early after the translocations (Vandel et al. 2006, Yiu et al. 2015)

The Eurasian lynx (*Lynx lynx*) is a solitary predator with a social organisation based on territoriality. The species has one of the most widespread distributions of the currently living felids (Breitenmoser et al. 2015), but in many parts of Europe, their populations are highly fragmented and at risk of extinction (Kaczensky et al. 2013). The Dinaric-SE Alpine lynx population went extinct at the beginning of the 20th century due to hunting and persecution, habitat loss and lack of prey species. It was successfully reintroduced in 1973 by translocating six animals from a Carpathian source to Slovenia. The animals then spread towards the southeast to Croatia and Bosnia and Herzegovina, as well as to Italy in the west and Austria in the north (Sindičić et al. 2013). However, at the beginning of the 21st century, genetic analysis showed that a founder effect and absence of natural migrations from any other lynx population caused low effective population size and considerable inbreeding (Sindičić et al. 2013). Therefore, the conclusion was that genetic factors, additive to threats like human–induced mortality (Sindičić et al. 2016) and prey base depletion, can quite possibly lead to another extinction of this species from the Dinaric Mountains (Sindičić et al. 2013). So today, the Eurasian lynx is regarded as the most endangered mammal in the region, with minimum population estimates of 95 adult lynx distributed along 12,500 km^2 in Slovenia and Croatia (Gomerčić et al. 2021, Fležar et al. 2022) and an unknown population status in Bosnia and Herzegovina. To save the population from extinction, urgent measures were needed to improve the genetic status and connectivity with other populations. For that reason, 11 partners from five countries came together under the LIFE Lynx project (LIFE16 NAT/SI/000634) with the primary goal of improving the genetic and demographic outlook of the Dinaric-SE Alpine population through reinforcement (Černe et al. 2019).

Data from different regions report that the Eurasian lynx mating season lasts from February to mid-April, and in late May, females usually give birth to an average of 1-4 kittens (López-Bao et al. 2019). The timing of the first dispersal of young lynx ranges from 8.1 to 10.7 months and does not differ between males and females (Zimmermann et al. 2005). After separating from their mother, young lynx stay for a few days in the maternal home range before they disperse (Zimmermann et al. 2005). In Sweden, telemetry studies showed that about one-third of Eurasian lynx female offspring remained philopatric (Samelius et al. 2011), indicating the potential for geographic clustering of female relatives. Lynx diet varies considerably among different regions (Okarma 1984, Gossow & Honsig-Erlenburg 1985, Pulliainen et al. 1995, Pedersen et al. 1999, Breitenmoser & Breitenmoser-Würsten 2008), while the main prey of Dinaric lynx is roe deer (*Capreolus capreolus*) (Krofel et al. 2011).

Our study investigated space use and exploratory movement patterns of six Eurasian lynx subjected to "forced dispersal" as part of a reinforcement process (Černe et al. 2019). Data used in this study were acquired during the first three months post-release to provide an in-depth analysis of the early behaviour of translocated lynx. No previous research investigated the early behavioural response of Eurasian lynx individuals engaged in a population reinforcement process, so we decided to limit the data to only three months post-release to understand this critical period thoroughly. Directions of movements and straight-line distances were calculated and compared over time, as well as total distance (TD) from the release sites and time to the initial settlement, defined as a polygonal movement with the decrease and stabilisation in distance from the release site. We predicted that the calculation of the TD would show a clear difference between the exploratory movement TD and home-ranging TD in translocated animals. The movement patterns of translocated animals and their temporal dynamics should indicate the establishment process of individual animals (Berger-Tal & Saltz 2014). We expect an initial increase in distances from the release site during exploration and stabilisation or reduction when the animal has settled. Lastly, we compared the orientation of lynx movement in relationship to terrain aspect, slope and elevation as we expected the lynx to use ridges for their movement in mountainous landscapes (Zimmermann et al. 2007).

Study Area

The study area includes four release sites within the lynx distribution area (Gomerčić et al. 2021, Fležar et al. 2022) in the Dinaric Mountains in Croatia and Slovenia (Fig. 1): 1) Kočevsko-Belokranjska region (Slovenia): hunting ground "Loški Potok"; 2) Notranjska region (Slovenia): hunting ground "Jelen", Snežnik; 3) Primorsko-Goranska county (Croatia): National Park "Risnjak"; and 4) Zadarska and Ličko-Senjska county (Croatia): National Park "Paklenica".

Release sites were selected following the protocols of the LIFE Lynx project (LIFE16/NAT/SI/000634) that took into account the presence of other lynx individuals (investigated using camera traps) (Slijepčević et al. 2019), local stakeholder acceptance (Majić-Skrbinšek et al. 2020) and human-induced mortality risks. As the literature review showed no obvious advantages for soft or hard release (Wilson 2018), based on the technical and financial capacities of project partners and hunters' active involvement, a soft release was implemented in Slovenia and a hard release in Croatia.

Predominant habitats in Croatia and Slovenia are rugged karst terrains with mixed forests of European beech and mixed oak forests that dominate at medium and low altitudes in a deep soil and humid slopes, valleys, and canyons. The dominant canopy tree species of the mountain conifer forests are spruce (*Picea abies*), silver fir (*Abies alba*), and black pine (*Pinus nigra*). The Dinaric karst region of Croatia and Slovenia is part of the Dinaric Mountain range, which belongs to the Alpine-Himalayan mountain belt. It spans in NW-SE direction from Slovenia through Croatia and Bosnia and Herzegovina up to Montenegro and northern Albania with altitudes ranging from sea level to 2,600 m a.s.l. (Ozimec et al. 2012). Dominant species of wild ungulates in the study area are roe deer, red deer (*Cervus elaphus*), wild boar (*Sus scrofa*) and chamois (*Rupicapra rupicapra*). There are also a few small and isolated introduced populations of mouflon (*Ovis ammon*) and fallow deer (*Dama dama*). Besides the Eurasian lynx, brown bear (*Ursus arctos)*, grey wolf (*Canis lupus*), and golden jackal (*Canis aureus)* are present in the area, as well as several species of smaller carnivores (Ozimec et al. 2014). Climatically, an average annual rainfall of 1,500-2,000 mm characterises this ecoregion with an annual temperature averaging 5-8 °C, ranging from a maximum of 32 °C in July to a minimum of –20 °C in January (Ozimec et al. 2014).

The release sites are all characterised by the *Omphalodo-Fagetum* forests with an additional Mediterranean habitat in National Park Paklenica (Southern Velebit Mt.). The seacoast limits animal movement around the Paklenica canyon from the SW side and agricultural fields and open space from the NE side. The southern side of the mountain Velebit is covered chiefly with dense shrub species typical of Mediterranean scrub. In contrast, the northern side is covered with mixed fir and beech forest (Ozimec et al. 2014).

Material and Methods

Seven lynx were released during 2019 and 2020, but we used telemetry data from six male Carpathian lynx, captured in Romania and Slovakia and released in the Dinarics for reinforcement. The telemetry collar from the seventh lynx, named Pino, stopped working immediately after the release in Croatia, so there were no available data, and Pino's fate is unknown. The six monitored lynx were named Goru, Doru, Alojzije, Catalin, Boris and Maks (Table 1). Five of them (all except Maks) were captured in box traps during the winter (January-March) in 2019 and 2020. They were kept in quarantine enclosures in the country of capture for at least three weeks before transportation to Croatia and Slovenia. Age estimation was done following Marti & Ryser-Degiorgis's (2018) classification while handling animals at the capture sites (Table 1). Lynx Maks was not captured but was found in poor health in the Poľana Protected Landscape Area in Slovakia due to a forelimb fracture. Besides leg injury and malnutrition, the animal was also infested with numerous parasites.

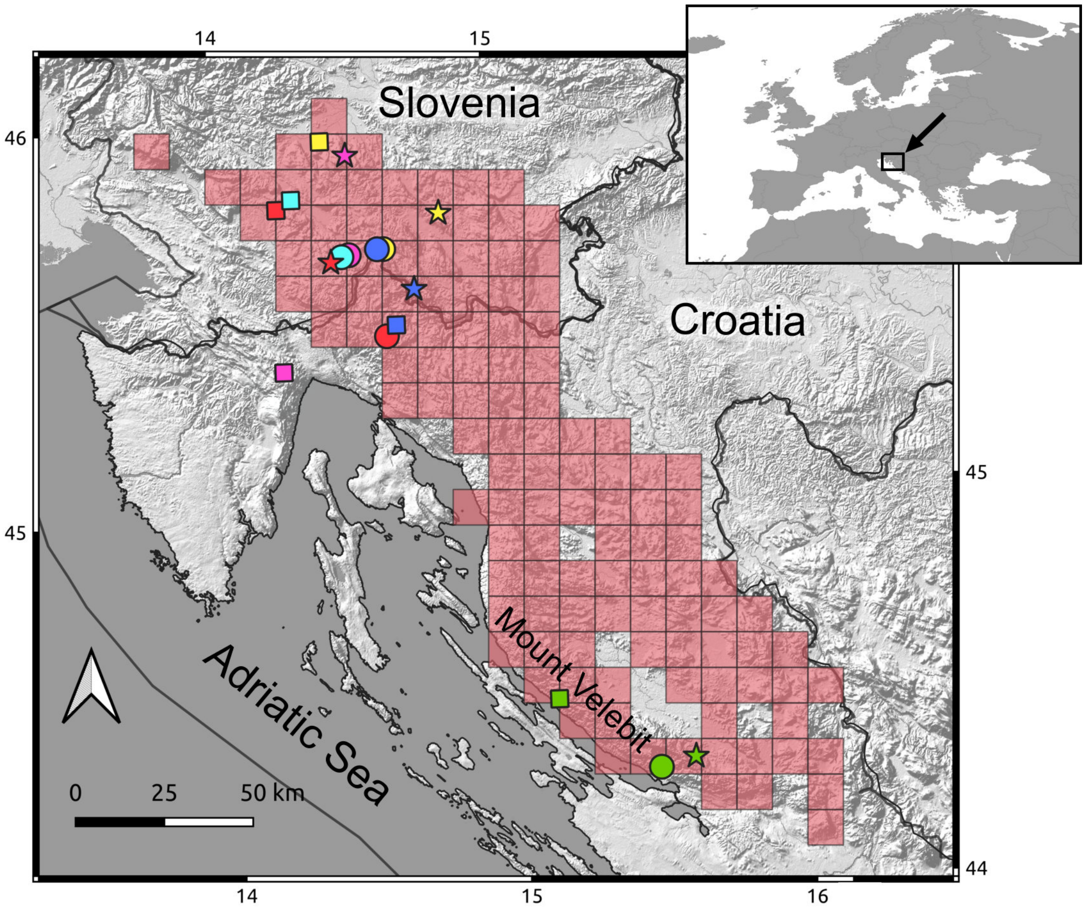

Fig. 1. Red 10 × 10 km quadrants indicate lynx distribution in Slovenia and Croatia. Each colour represents a different lynx individual: Doru (red), Goru (yellow), Alojzije (green), Catalin (rose), Boris (blue) and Maks (cyan). Release sites are presented with circles: hunting ground "Loški Potok" (blue and yellow), hunting ground "Jelen", Snežnik (cyan and rose), National Park "Risnjak" (red) and National Park "Paklenica" (green). Squares represent the farthest location reached from the release site by each lynx. Stars represent the location after which the movement pattern changed, indicating settlement.

Maks was transported and rehabilitated in the National ZOO Bojnice for nine months, after which he fully recovered. The team decided to translocate him to the Dinarics with other animals captured for repopulation within the LIFE Lynx project.

Two lynx (Doru and Alojzije) were hard released in Croatia at two release sites, and the other four were soft released in Slovenia at two release sites (Fig. 1). Due to technical and financial capacities, the hard release was used in Croatia, while in Slovenia animals were kept in an enclosure at the release site for at least two weeks after the transport from the country of origin and before the soft-release. Before the release, animals were equipped with the GPS-GSM-VHF telemetry collars (Vertex Lite, Vectronic Aerospace GmbH). Collars had different GPS schedules, set to collect GPS locations in intervals between 4 and 24 h.

We defined the early post-release period as three months (91 days) after the release. To analyse the lynx's first behavioural response, we assessed the movement patterns of released animals and their temporal dynamics. We defined straight-line movement and increased distance from the release sites as exploratory movement, while polygonal movement with decreased and stabilised distance indicated a settlement process (Bunnefeld et al. 2011).

The following variables were calculated using QGIS (Geographic information system, Open source geospatial foundation project 2020) (Table 1): 1) time (days) from the release site to initial settlement; 2) straight-line distance (SLD) from the release site to initial settlement; 3) total distance (TD) moved from the release site to initial settlement; 4) average daily distance (DD) (km/days); 5) maximum daily distance (km); 6) maximum aerial distance from release site (km); 7) min-max altitude (m a.s.l.); 8) direction of lynx movement; 9) terrain elevation, slope, forest cover and aspect; 10) time (days) until first kill detection; 11) the average number of kill sites during exploration movement; 12) the average number of kill sites during settlement.

Table 1. Data on movement and predation for six translocated male Eurasian lynx during 91 days after their releases. SLD – straight-line distance from the release site in kilometres, TD – total distance from the release site to initial settlement in kilometres, DD – daily distance.

Lynx	Estim. age (years)	Release site	Release date	Days until initial settlement	SLD (km)	TD (km)	DD (km/ days)	Max. daily distance (km)	Max. aerial distance from release site (km)	Min-max altitude (m a.s.l.)	Days until first kill	Total number of kill sites during exploration	Average days between kill sites during exploration	Average days between kill sites during settlement
Doru	4	Risnjak NP, CRO	4.5.2019	43	18	205	2.4	10.8	50.4	536-1,357	7	6	10.75	10.66
Goru	5	Loški Potok, SLO	14.5.2019	17	15	256	2.8	17.1	35.2	347-964	1	2	8.5	8.2
Alojzije	4	Paklenica NP, CRO	13.3.2020	42	8	255	2.7	9.8	35.1	476-1,637	3	2	7	6.75
Catalin	5	Snežnik, SLO	31.3.2020	20	24	358	4.2	14.4	34.2	340-1,434	6	4	10	8.87
Boris	1-2	Loški Potok, SLO	28.5.2020	15	14	97	1.1	7.8	20.6	316-1,160	10	2	7.5	5.2
Maks	2	Snežnik, SLO	23.6.2020	1	N/A*	N/A*	1.7	9.2	19.8	542-1,165	2	N/A	N/A*	6.9

*Lynx Maks did not show exploratory movement after release.

Straight-line distance (SLD) from the release site to initial settlement represents the aerial distance between the location of the release site and the location closest to the release site, after which the animal showed polygonal movement that indicated settlement.

For calculating the distance between daily locations, we chose 91 locations for each lynx taken on consecutive days at 24 h intervals. We chose 24 h intervals because, on some collars, that was the minimum scheduled interval. There were cases when the collar failed to fix the location, so we interpolated to 24 h intervals.

The total distance (TD) measures the sum of aerial distances between the starting location and the following location for the movement path of a given individual. Average daily distance (DD) measures the sum of aerial distances between two consecutive locations divided by the number of days in which this distance was attained. In comparison, the maximum daily distance represents the highest distance between two consecutive locations. The maximum aerial distance from the release site (km) presents the farthest overall location from the release site reached by each lynx.

The direction of movements was defined by calculating the bearing between two consecutive locations. Next, terrain characteristics were calculated in QGIS using a 5 km buffer around the animal's GPS locations (chosen as an assumed maximal distance an animal can perceive from a fixed point) (Boitani & Fuller 2000). We then took 5,000 random points inside the buffer for which we calculated aspect, slope angle and elevation from a dem30 map, in 1 × 1 km resolution (Gesch et al. 1999).

We compared (a) the aspect frequency of the actual terrain used by the six lynx (5,000 random points inside a 5 km buffer around all lynx locations) with the aspect frequency of a universal terrain. Universal terrain is a hypothetical terrain with the same aspect frequency in all compass directions from 0° to 360°. Next, to compare between the use and availability of the terrain; (b) we overlapped the frequency of movement direction of the lynx with an aspect frequency of the actual terrain. The goal was to define whether the terrain aspect influences lynx exploratory movement. We used R package Overlap (Ridout & Linkie 2009) to calculate the coefficient of overlapping (Table 2). The smaller the coefficient (a) is, the more the actual terrain differs from universal terrain, i.e. elongates in a specific direction. The smaller the coefficient (b) is, the more lynx movement follows the mountain direction, while a higher coefficient indicates that the lynx movement is more perpendicular to the mountain. To test this presumption, we also (c) overlapped the frequency of lynx movement direction with an aspect frequency of universal terrain and compared the coefficients ((a) *vs.* (c)). If (a) is smaller than (c), it confirms that lynx movement follows the mountain direction and *vice versa*. For calculating the coefficient of overlapping, we used Dhat 1 estimator because we had less than 50 locations (movement directions) for each lynx. We standardised the variables aspect and converted the degrees of the terrain aspect and lynx movement direction (0-360°) to a normalised 0-1 range.

Kill sites were detected using three GPS collar locations in a period longer than 30 h within 300 m, following the GPS location cluster analysis described by Krofel et al. (2013). Forest cover analyses were done using the CORINE Land Cover inventory for 2018 (Büttner et al. 2021). All shapefiles were projected as the HTRS96/UTM zone 33N coordinate system.

Results

Six male lynx were monitored with GPS-GSM-VHF telemetry collars throughout the early post-release period (i.e. three months after the release). All animals settled during this period, on average 23 days (SD = 16.5) after the release.

Doru

Lynx Doru (Fig. 2) was hard-released at 707 m a.s.l., surrounded by mountain ridgelines above 1,000 m a.s.l. The first day after the release, Doru moved 3.8 km and climbed to 1,180 m a.s.l. For the next two weeks, he stayed within 6.2 km from the release site keeping his average altitude at 1,074 m a.s.l. He started distancing himself gradually on the 17th day, with the peak on the 60th day when he was 50 km away from the release site and was stopped by the A1 Ljubljana-Koper highway in Slovenia. From there, he started showing settlement indicating polygonal movement (Fig. 1). Average altitude during his exploratory movement was 1,021 m a.s.l. and 796 m a.s.l. during settlement indicating movement. His average speed showed no difference in exploratory movement (N = 2.2 km/daily) *vs.* moving in his home range (N = 2.5 km/daily) in the monitored period. His first kill site was detected seven days after the release while the average time between kill sites during the exploration phase was 10.75 days.

Goru

Lynx Goru (Fig. 3) was released after an 18-day stay at the soft-release enclosure at 894 m a.s.l. The first day after the release, Goru made 4.8 km, crossed the border to Croatia and stayed in that range at 916 m a.s.l. for three days, after which he returned to Slovenia. He reached the farthest point from the release site eight days post-release and then, after reaching the lowland agricultural landscape around Ljubljana, he turned East. His average altitude during exploratory movement was 712 m a.s.l. and 672 m a.s.l. during settlement indicating movement. His average speed was 5.9 km/daily and dropped to an average of 2.1 km/daily after he started showing polygonal movement. His first kill site was detected already the first day after the release while the average time between kill sites during the exploration phase was 8.5 days.

Alojzije

Alojzije (Fig. 4) was hard-released inside the Paklenica canyon at 624 m a.s.l. For the first three days, he stayed less than 400 m from the release site and for two weeks within 6 km from the release site with an average altitude of 807 m a.s.l. and a maximum of 1,308 m a.s.l. He reached the maximum distance from the release site on the 33rd day when he was 35 km away from the release site. His average altitude during exploratory movement was 882 m a.s.l. and 792 m a.s.l. during the settlement indicating movement. His average speed was 2.2 km/daily while in exploratory movement *vs.* 3.3 km/daily after he started showing polygonal movement. His first kill site was detected three days after the release, while the average time between kill sites during the exploration phase was seven days.

Catalin

Lynx Catalin (Fig. 5) was released after a 24-days stay at the soft-release enclosure at 979 m a.s.l. Catalin started to move away from the release site from the first day post-release and climbed to 1,434 m a.s.l. In the next few days, he continued his exploratory movement and distanced for 15.2 km from the release site, crossing the border to Croatia. After two weeks, he returned to Slovenia and was 32 km away from the release site when he travelled 14 km in one day, which was his maximum daily distance in the monitoring period. He reached his maximum distance from the release site on the 66th day when he was already showing polygonal movement. His average altitude during the exploratory movement was 782 m a.s.l. and 709 m a.s.l. during the settlement indicating movement. While in exploratory movement, Catalin's average speed was 9.1 km/daily, which dropped to an average of 2.8 km/daily after he started showing polygonal movement. His first kill site was detected six days after the release, while the average time between kill sites during the exploration phase was ten days.

Boris

Lynx Boris (Fig. 6) was released after a 28-day stay at the soft-release enclosure at 894 m a.s.l. The next day, he climbed to 1,097 m a.s.l. and stayed under 3 km distance for the first week after the release and started moving farther on the 10th day when he travelled 6 km in a day and soon afterwards crossed the border to Croatia. He reached the farthest point from the release site on the 50th day of the monitoring period. His average altitude while engaged in exploratory movement was 941 m a.s.l. and 571 m a.s.l. His

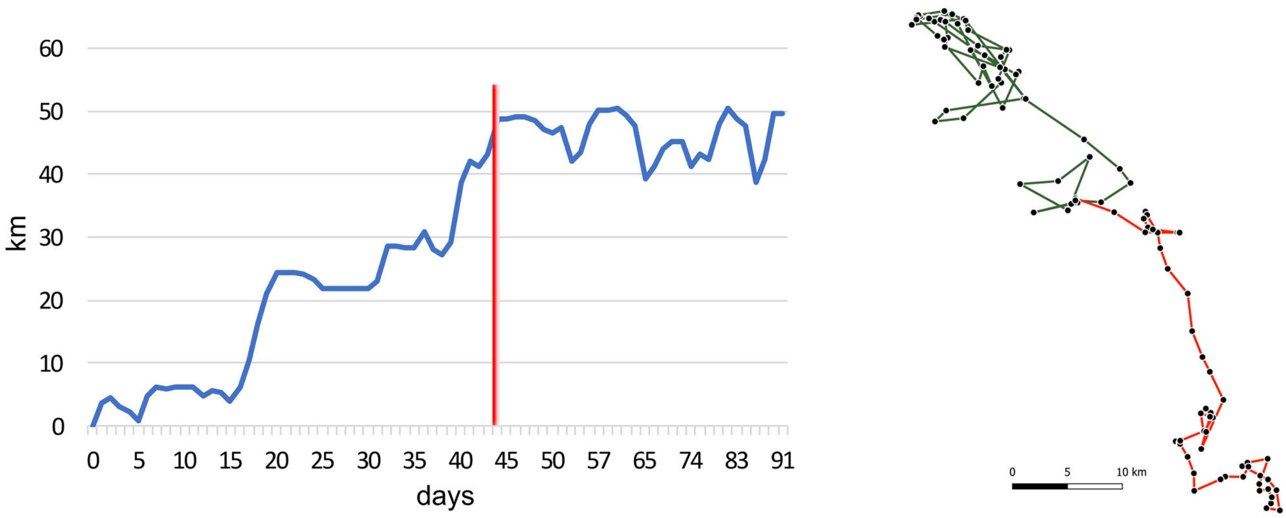

Fig. 2. Left: movement (kilometres over time) for male lynx Doru with mixed movement pattern line – indicating exploratory movement pattern and after the red line the start of settlement pattern. Right: Doru's exploratory movement (red) and settlement indicating movement (green).

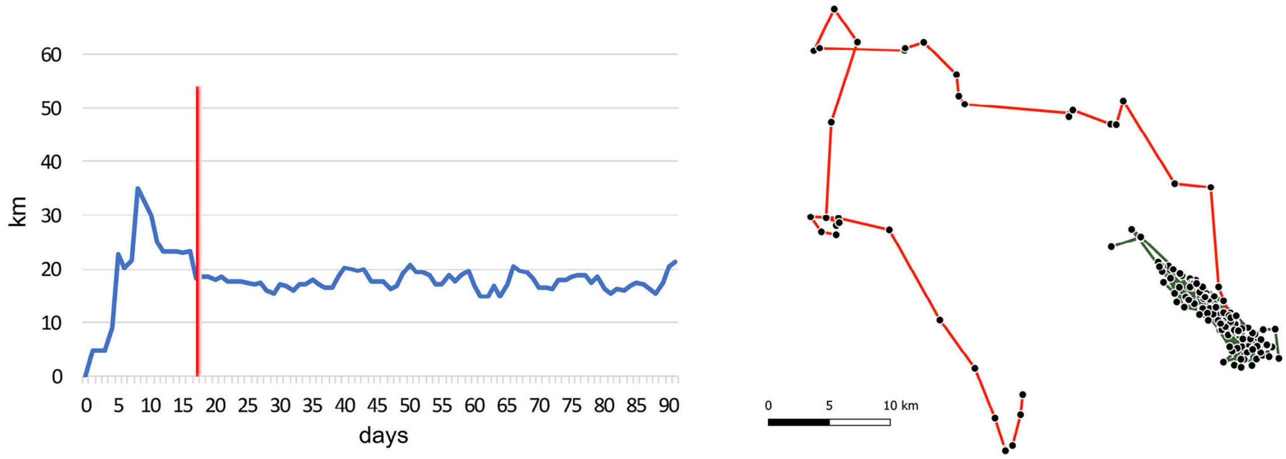

Fig. 3. Left: movement (kilometres over time) for male lynx Goru with mixed movement pattern line – indicating exploratory movement pattern and after the red line the start of settlement pattern. Right: Goru's exploratory movement (red) and settlement indicating movement (green).

average speed was 1.8 km/daily during exploratory movement and 1.1 km/daily after showing polygonal movement. His first kill site was detected ten days after the release, while the average time between kill sites during the exploration phase was 7.5 days.

Maks

Lynx Maks (Fig. 7) was released after a 20-day stay at the soft-release enclosure in the area of Snežnik, Slovenia (979 m a.s.l.). The first three days after the release, he stayed within 2 km of the release site and climbed to 1,153 m a.s.l. On the third day, he started distancing gradually and 18 days post-release he reached 19.8 km from the release site when the A1 Ljubljana-Koper highway stopped him. His average altitude was 774 m a.s.l. His average speed was 1.7 km/day. Maks showed only polygonal movement between the release site and the highway inside the monitoring period (91 days), so we have not registered clear exploratory movement behaviour. His first kill site was detected two days after the release and the average time between kill sites was 6.9 days.

First kill sites of all animals were detected in the first ten days (SD = 1.7), on average, 3.4 days after the release. The average number of days between the kill sites for all lynx during exploration was 8.75 days, while after settlement, the average was 7.76 days between kill sites (Table 2). The main exploratory movement direction of the released animals was NW-SE, corresponding to the orientation of the predominant ridgelines of the Dinaric Mountain range (Fig. 8.)

Forest cover was primarily uniform, and five out of six lynx moved on a terrain with a high percentage of forest cover, while Alojzije used terrain covered with forests and shrublands, typical habitat for the southern part of mountain Velebit, where he was released and established a territory (Table 2).

When we compared the coefficients of the overlap between the direction of movement of the lynx and the aspect of the natural and universal terrain for all released animals, the coefficient of overlap was smaller in the actual terrain than in the universal terrain (Table

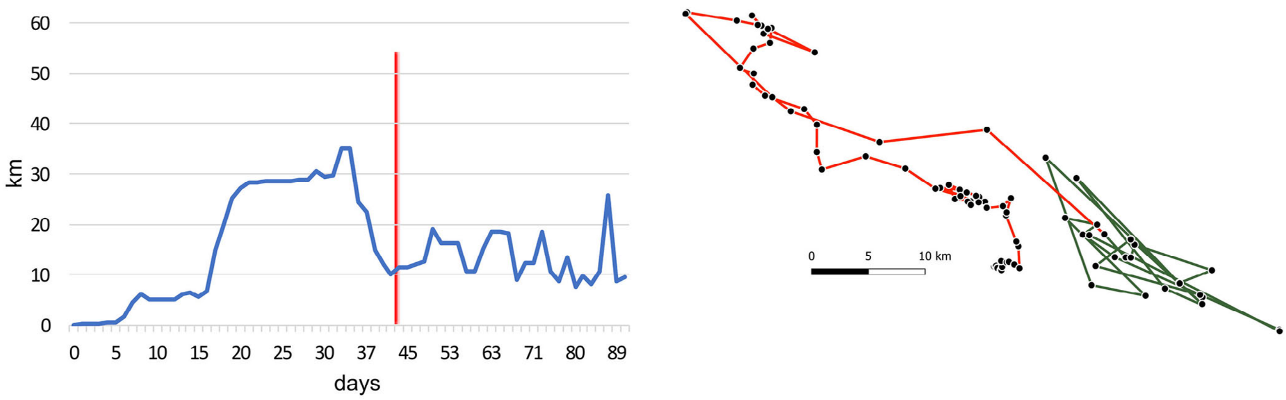

Fig. 4. Left: movement (kilometres over time) for male lynx Alojzije with mixed movement pattern line – indicating exploratory movement pattern and after the red line the start of settlement pattern. Right: Alojzije's movement during exploratory movement (red) and settlement indicating movement (green).

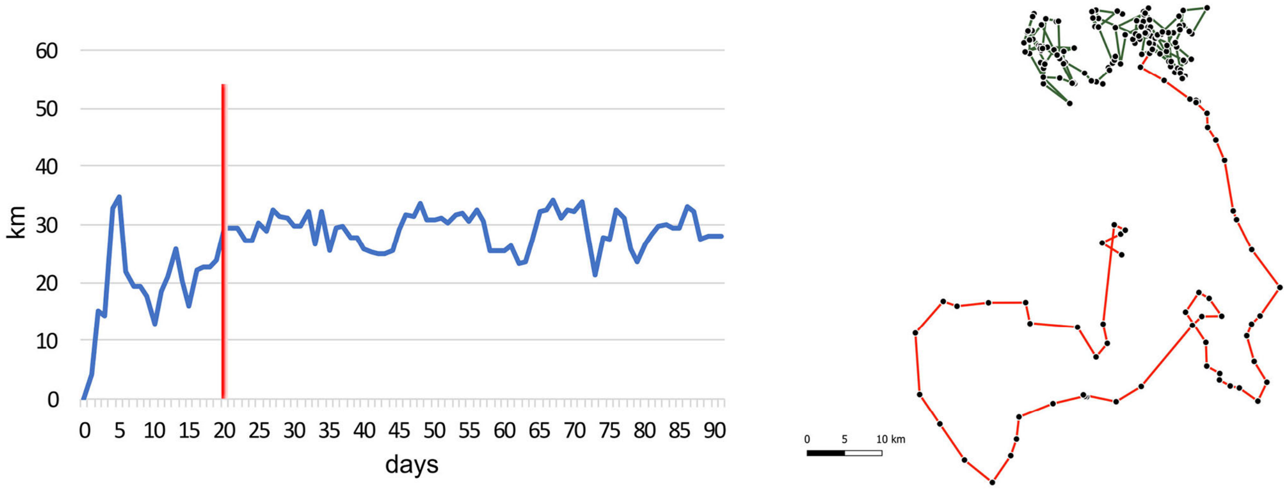

Fig. 5. Left: movement (kilometres over time) for male lynx Catalin with mixed movement pattern line – indicating exploratory movement pattern and after the red line the start of settlement pattern. Right: Catalin's movement during exploratory movement (red) and settlement indicating movement (green).

2). This finding indicates that all lynx movement directions matched the actual terrain's directions. The largest difference between the coefficient of the natural and universal terrain was recorded in the case of lynx Alojzije, which could be explained by the fact that the terrain he used for exploratory movement was the steepest (Table 2). Fig. 9 compares the frequency of Alojzije's movement directions with frequencies of the aspect of the actual surrounding terrain. The observed low overlap indicates that Alojzije avoids going up or down the slopes (Fig. 9).

Discussion

Information on Eurasian lynx exploratory movements after translocation is rare in the scientific literature (Vandel et al. 2006) and found only in the grey literature, such as project reports in the respective countries' native languages (Ryser et al. 2004). Once released into the wild, animals can choose to stay near the release site or to move away from it (Berger-Tal & Saltz 2014). Homing behaviour is typical in re-introductions, when animals tend to travel towards the direction of their capture sites after release (Rogers 1988). Such behaviour has been interpreted as a rejection of the forced dispersal and typically results in low site fidelity, i.e. animals are unwilling to settle in the new area (Miller et al. 1999).

Personality may also play an important role in the movement response (Spiegel et al. 2017, Rueda et al. 2021), as well as the survival of reintroduced individuals (Bremner-Harrison et al. 2004). Five out of six lynx from our study showed exploratory movement behaviour after the release. The six lynx established their territories after an average of 23 days (SD = 16.5) post-release. They settled on average 15.8 km (SD = 5.8) from the release sites,

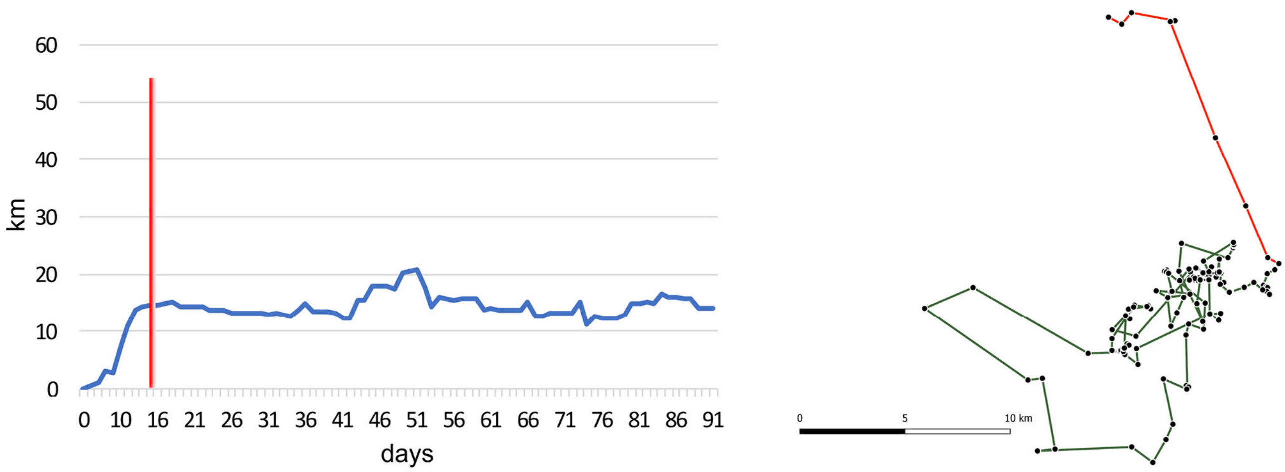

Fig. 6. Left: movement (kilometres over time) for male lynx Boris with mixed movement pattern line – indicating exploratory movement pattern and after the red line the start of settlement pattern. Right: Boris's movement during exploratory movement (red) and settlement indicating movement (green).

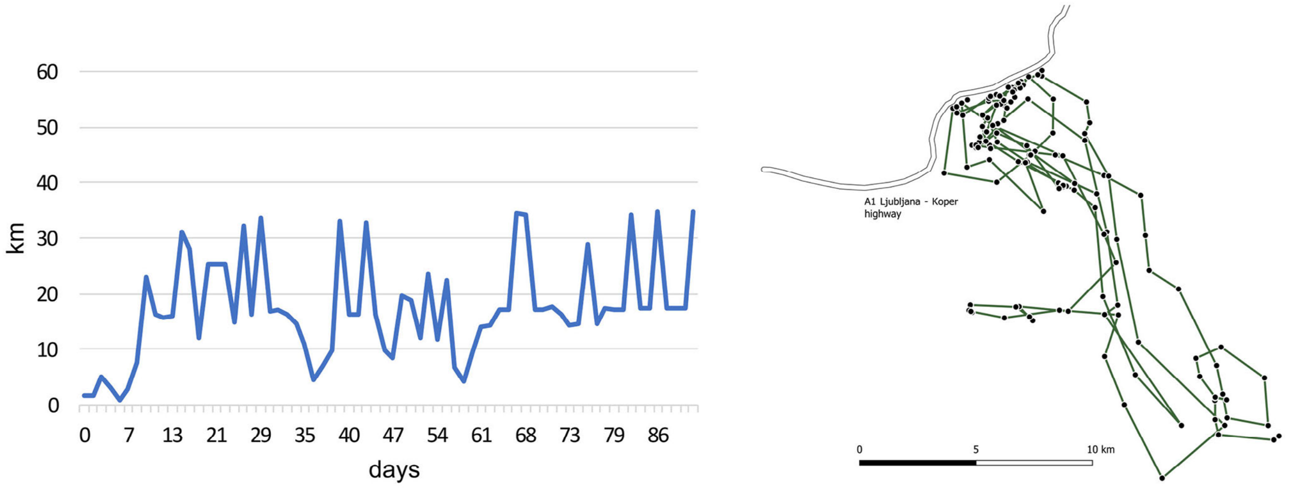

Fig. 7. Left: movement (kilometres over time) for male lynx Maks with settlement indicating movement pattern line. Right: Maks's movement after release showing polygonal movement.

which corresponds to the results from the Swiss project report on the exploration movement of lynx translocation in north-eastern Switzerland (Ryser et al. 2004). First kill sites of all animals were detected on average 3.4 days after the release. The average time between kill sites after settlement was 7.76 days (SD = 1.91) which corresponds to the kill rate of resident Dinaric lynx (Krofel et al. 2013). Unfortunately, data on lynx prey densities are unavailable for the entire study area. However, our results concerning the kill rates of released lynx did not indicate the lack of prey availability around the release areas. Although it is outside of the period which is the focus of this study, we emphasise that Boris and Maks left their first

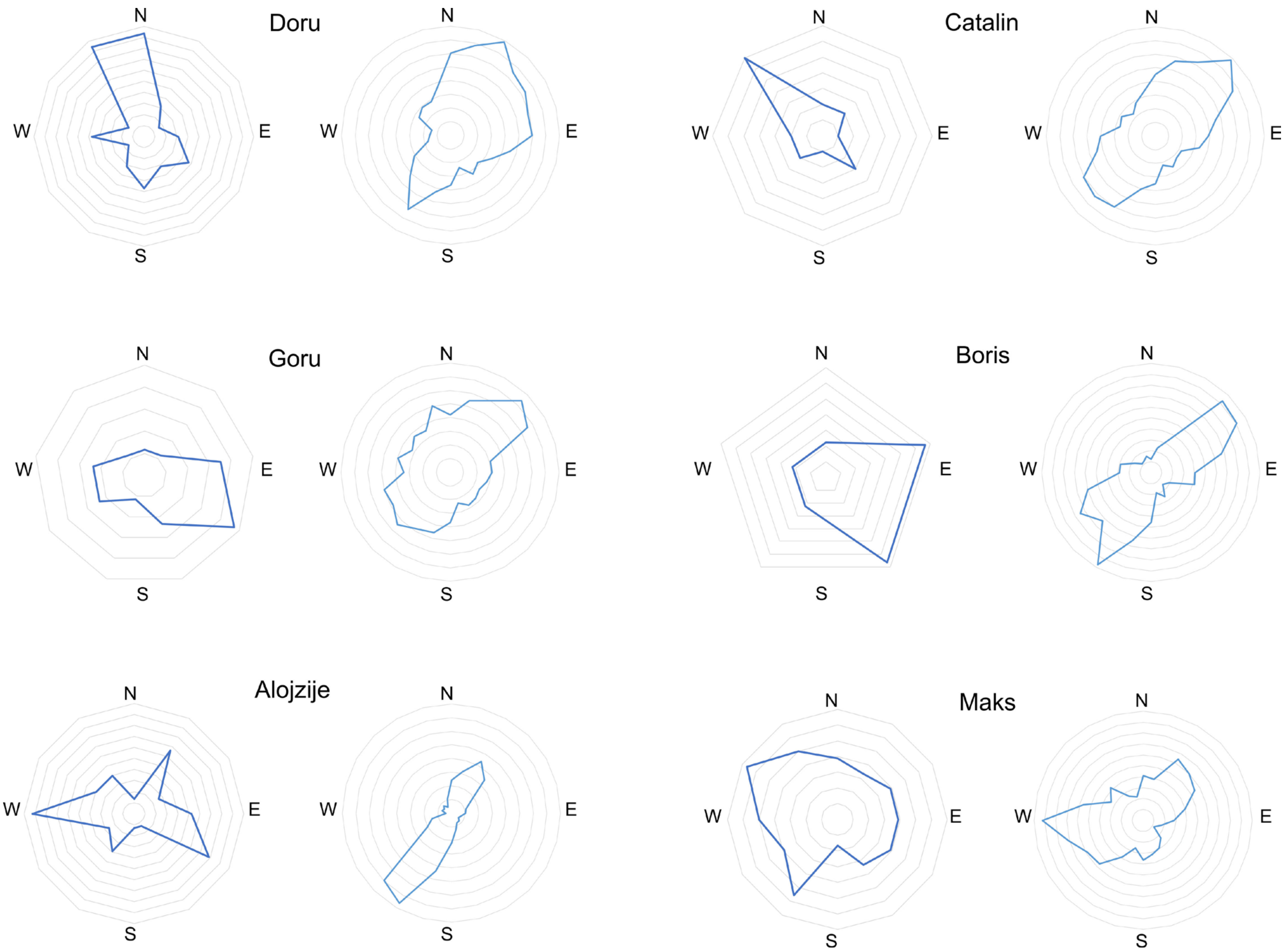

Fig. 8. Direction frequency calculated for each lynx movement 0-360° (left) and corresponding habitat characteristic concerning terrain exposition frequency 0-360° (right) calculated from the 5 km buffer around each animal's GPS locations.

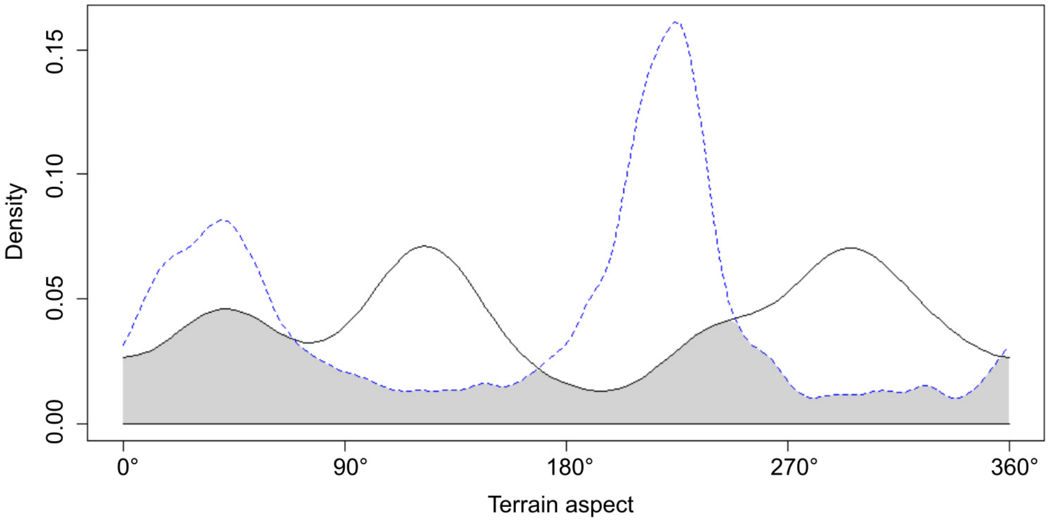

Fig. 9. Graph showing the overlap of lynx movement direction with the aspect of surrounding terrain in the case of lynx Alojzije. Blue intermittent line – terrain aspect; solid black line – lynx movement aspect. The peaks on the intermittent line in the area of 40° (NE) and 200° (SW) show that the slopes are oriented in these directions, i.e. that the mountains spread in the opposite direction of 130° (SE) and 280° (NW). The peaks on the solid line in the area 110° (SE) and 290° (NW) show the most common directions of lynx movement. The grey area of the overlap presents the value of the overlapping coefficient.

territory 102 days (Boris) and 92 days (Maks) after the release and started a second exploratory movement. Boris settled approximately two months later in Croatia, 64 km of straight-line distance from his first territory, while Maks moved 18 km north and stayed again close to the highway for two months before he managed to cross it (Krofel et al. 2021).

Before he was soft-released, Maks spent nine months in the rehabilitation centre in Slovakia and 20 days in the enclosure at the release site in Slovenia. Unfortunately, our sample size was too low to statistically analyse the influence of hard *vs.* soft release (and time spent in the enclosure) on the exploratory movement of the released animals. Also, it is hard to hypothesise whether his behaviour was affected by the rehabilitation process, his young age or the A1 Ljubljana-Koper highway that limited his exploration. However, this individual and others released confirmed that the A1 Ljubljana-Koper highway presents a significant anthropogenic barrier (Krofel et al. 2006, Skrbinšek & Krofel 2008) for lynx movement from the Dinaric Mountains towards the Alps. Zimmermann et al. (2007) study showed that

Table 2. Terrain characteristics and coefficients of overlapping for six reintroduced lynx.

	Elevation average (min-max)	Slope	% under forest	Dhat1 (b)	Dhat1 (a)	Dhat1 (c)
Alojzije	811 (1-1,653)	8.6	52.5	0.64	0.54	0.82
Boris	830 (309-1,207)	6.7	96.4	0.73	0.58	0.65
Catalin	791 (301-1,707)	4.9	95.5	0.88	0.69	0.77
Doru	967 (328-1,628)	5.0	94.3	0.84	0.81	0.83
Goru	626 (268-1,180)	4.2	96.0	0.82	0.65	0.75
Maks	745 (426-1,241)	4.0	99.7	0.82	0.81	0.9

a – coefficient of overlapping between aspect frequency of real terrain with aspect frequency of universal terrain. b – coefficient of overlapping between frequency of movement direction of lynx with an aspect frequency of real terrain. c – coefficient of overlapping between frequency of movement direction of lynx with an aspect frequency of universal terrain.

subadult lynx have a low capability to move through unfavourable habitats and cross linear barriers such as fenced highways. Lynx Maks reached the highway 18 days post-release and was forced to stay on the terrain south of the highway with several unsuccessful attempts of crossing, which likely influenced his settlement behaviour. He crossed the highway four months after reaching this barrier for the first time and soon after undertook a second exploratory movement (Krofel et al. 2021). The other two translocated lynx that reached this highway (Doru and Catalin) never managed to cross it. Such poor connectivity presents a threat to populations already fighting with inbreeding. Creation and maintenance of functional linkages between remnant populations should become a conservation priority, and resources must be dedicated to enhancing habitat networks that allow natural gene flow among populations. Given the results presented in this study, we urge responsible institutions to prioritise the construction of wildlife passes suitable for lynx on the A1 Ljubljana-Koper highway, specifically at the section identified as an essential wildlife corridor in this study (highway section Unec-Postojna).

Besides the barriers, landscape heterogeneity significantly shaped exploratory movement directions and provided an efficient tool for understanding the decision-making of the animals. Our results showed a preference for NW-SE exploratory movement direction, corresponding to the orientation of the predominant ridgelines of the Dinaric Mountain range. Zimmermann et al. (2007) showed the same exploratory movement pattern in the Jura Mountains that run SW-NE, which appeared to shape the exploratory movements of subadult lynx. On the contrary, in the north-western Swiss Alps, where parallel ridgelines are not present, movement directions were oriented randomly (Zimmermann et al. 2007). Furthermore, when we compared the coefficients of the overlap between the direction of movement of the lynx and the aspect of the universal and actual terrain, in the case of all released animals, the coefficient of overlap was smaller in the actual terrain than in the universal terrain. From this, we concluded that the lynx chose to move along the mountain range and not perpendicular to the mountain, i.e. they avoided moving uphill and downhill. The largest difference between the actual and universal terrain coefficient was recorded in the case of lynx Alojzije, which could be explained by the fact that the terrain he was using for exploratory movement was the steepest. We are aware that the orientation of the mountain range consequently affects the orientation of the roads, water streams and saddles which can also affect space use and lynx movement direction; however, the lack of such data impaired us from using parameters other than terrain characteristics presented in our study. Nevertheless, we encourage researchers to include more parameters in future studies to describe and quantify local relief.

Compared to other studies (e.g. Nathan 2008, Bunnefeld et al. 2011), our results showed apparent changes in lynx movement behaviour, which we used as an indication of the settlement process of individual animals. Once the animal's daily distance from the release site stabilised and the animal started moving in a polygonal pattern, the graphic presentation of TD showed a clear difference in exploratory movement TD and home range TD. The observed difference showed that all six lynx had established temporary home ranges. However, two of them later abandoned them and moved further (likely due to the presence of another territorial male known from a camera trapping survey (Krofel et al. 2021). Berger-Tal & Saltz (2014) explained the same pattern in theory, where they presented how the knowledge gained in unfamiliar novel environments should be followed by a subsequent change in an animal's movement behaviour, making movement behaviour an excellent indicator of the establishment process.

In-depth analysis of the early movement behaviour of translocated lynx enabled us to describe the average time until territory establishment, their movement and feeding patterns and helped us identify potential habitat connectivity problems. One of the biggest challenges when planning re-introduction is to ensure that released animals will settle within the desired area. Among our translocated animals, the maximum aerial distance reached from the release site was 50 km. At the same time, the Swiss results showed that an individual could move up to 60 km in the early post-release period (Ryser et al. 2004). Therefore, we advise that release locations are at least 60 km away from the borders of the targeted settlement area, such as national borders or protected areas, i.e. where monitoring of released individuals will not be compromised. Also, finding a balance between the quality and duration of telemetry monitoring is challenging. More GPS locations will provide better insight into animal movement, monitoring of their predation, and enable potential reactions if problems arise. But more locations will decrease battery life duration and will jeopardise possible termination of telemetry monitoring. Our finding that released lynx established their territory on average 26 days post-release can help plan the optimal collar schedule. We suggest that for the first 30-45 days after the release, collars are programmed to establish more frequent locations to monitor exploratory movement and fewer locations to enable prolonged monitoring and reduce risks connected to recapturing the animal to change the collar. We recognise the limitations of our study regarding the relatively small all-male sample size, but this study has already highlighted valuable theoretical and practical results. As the Dinaric lynx population reinforcement within the LIFE Lynx project will proceed until the year 2023, further analyses are planned based on a larger and more diverse sample size regarding sex and age structure, as well as a more extended monitoring period.

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Author Contributions

I. Topličanec and T. Gomerčić conceived and designed the study. All authors participated in fieldwork and data collection while I. Topličanec and T. Gomerčić analysed the data. I. Topličanec and M. Sindičić led the writing, while M. Krofel, R. Černe and S. Blašković improved the manuscript with their valuable comments.

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