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The Eurasian lynx in Continental Europe

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Cover Photo: Camera trap picture of two Eurasian lynx kittens in north-eastern Switzerland. 11 December 2014 (Photo KORA).

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Challenges in the conservation of Eurasian lynx in continental Europe – an introduction

The Eurasian lynx *Lynx lynx* once colonised all Continental Europe but was ousted gradually with the decrease of forests and wildlife on the one hand and the growth of the human population, the expansion of cultivated land and the increase of livestock. The final eradication of the remnant populations happened in the course of the 19th century. The exceptions were the populations in the north-east-ern European lowland, the Carpathians and the southern Dinaric Range, which all reached a minimum in the late 1940s, but eventually survived (for a review of the historic downfall and the source literature see Breitenmoser & Breitenmoser-Würsten 2008). Reintroduction programmes started almost 50 years ago, mostly, but not exclusively using funder animals from the Slovakian population. To date, Eurasian lynx were reintroduced in Continental Europe in France, Switzerland, Germany, Poland, the Czech Republic, Italy, Austria, and Slovenia (see contributions in this Special Issue). Some reintroduction projects failed at an early stage, and all emerging reintroduced populations are still relatively small, mostly isolated and show a rather high degree of inbreeding, inter alia because of the limited number of funder individuals (Breitenmoser & Breitenmoser-Würsten 2008).

At present, Continental Europe hosts 3 small to medium-size autochthonous and 11 tiny to small reintroduced populations distributed over 23 countries (von Arx et al. 2021). In recent years, new reintroduction projects were initiated (e.g. Idelberger et al. 2021, Tracz et al. 2021), efforts to connect distinct populations were made (Molinari et al. 2021) and the genetic remedy of earlier reintroduced populations was discussed and – in one case (Fležar et al. 2021) – already launched. Such projects require access to adequate source animals and the transport of translocated lynx across international borders. According to the IUCN Guidelines for Reintroductions and other Conservation Translocations (IUCN/SSC 2013), but also to EU and/or national legislation, such conservation interventions require the identification of the adequate source population, an evaluation of the conservation status of the source population, and veterinary health precautions to prevent the transmission of pathogens. However, the "traditional" source population of the Carpathian Mountains and mainly from Slovakia has its own conservation issues (Kubala et al. 2021), which triggered (again) the discussion on the use of conservation breeding programmes as a source for reintroductions (Lengger et al. 2021). Eventually, all these now isolated populations should be merged into few large and viable metapopulations to mitigate the negative effects of habitat fragmentation (Premier et al. 2021). But to complicate the picture, continental Europe hosts three phylogenetically distinct lines of Eurasian lynx, recognised as valid subspecies (Kitchener et al. 2017). Hence, is any lynx welcome anywhere? How shall we delineate areas of subspecies in regions where we have no information on the original inhabitants?

Such questions and the complex situation call for a consensual strategy for the long-term goals for the recovery of the Eurasian lynx, for agreed standards and protocols fa-

Fig. 1. The "Bonn Lynx Expert Group" – participants of the Bonn workshop 16–19 June 2019 (Photo A. Prüssing).

cilitating the international and interregional cooperation, and for common guidelines and a coordinated approach to lynx conservation in Continental Europe. Topical challenges are e.g. (1) the delineation of conservation units, (2) the genetic remedy of inbred populations, (3) the source populations for further translocations, (4) the connectivity of small populations, and (5) the management of lynx populations with regard to their coexistence with people.

On 16–19 June 2019, some 50 lynx experts (Fig. 1, Appendix I) gathered in Bonn to discuss the conservation of the Eurasian lynx in Continental Europe. The participants of the workshop aimed (1) to review the conservation status of continental lynx populations and the implementation of conservation projects, (2) to discuss recommendations for a coordinated long-term approach to lynx reintroduction and conservation across Western and Central Europe, and (3) to agree on the development of standards and shared protocols for the practical conservation work. The proceedings of the symposium are compiled in this Special Issue.

After the review, the participants developed Recommendations (Bonn Lynx Expert Group 2021) to help coordinating the conservation of the lynx in Continental Europe. The results from the Bonn Workshop were submitted to the Secretariat and the Standing Committee of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) of the Council of Europe, which on 6 December 2019 adopted the Recommendation No. 204 (Standing Committee 2019), which are congruent to the Recommendations presented at the end of this Special Issue (Bonn Lynx Expert Group 2021,).

Continental Europe, in the context of the following Proceedings and Recommendations, refers to the historic and present distribution range of the Eurasian lynx south of the large autochthonous populations of Fennoscandia and Russia. The Bonn conference concentrated on the biological and ecological aspects with regard to the recovery of viable lynx metapopulations in this region. Although we are fully aware of the importance of the human dimension aspects of such an endeavour, we were, for practical reasons, not able to address also the social science aspects of lynx conservation. However, all participants agreed that the discussions in Bonn should be continued and that further topics of lynx conservation in Continental Europe need to be addressed in the future.

The Bonn lynx conference was jointly organised by the HIT Umwelt- und Naturschutz Stiftung, the Stiftung Natur und Umwelt (SNU) Rheinland-Pfalz, the IUCN SSC Cat Specialist Group, and the Foundation KORA. Financial support was generously provided by the HIT Umwelt- und Naturschutz Stiftung, the SNU, and the Council of Europe (Bern Convention).

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Conservation status of the Eurasian lynx in West and Central Europe

With a total of 17,000–18,000 individuals including European Russia, the Eurasian lynx *Lynx lynx* is listed Least Concern at the European level in the IUCN Red List. However, some of the larger autochthonous populations in Scandinavia and the Baltics have shown declining trends in the past decade, and the Balkan lynx subspecies was assessed as Critically Endangered. The reintroduced populations in West and Central Europe remain small and are classified as Endangered (Alpine, Jura, Dinaric) or Critically Endangered (Vosges-Palatinian, Bohemian-Bavarian-Austrian, Harz). We present each of the populations regarding population numbers, range and threats and provide the justification for the respective Red List classifications.

The first Pan-European reports on the conservation of the Eurasian lynx were commissioned by the Council of Europe and provided information on the status in the 1980s (Breitenmoser & Breitenmoser-Würsten 1990) and early 1990s (Breitenmoser et al. 2000). Subsequently, the status of lynx was compiled and assessed not only at country level, but also for each population; 10 of the 11 lynx populations in Europe are transboundary (von Arx et al. 2004). The IUCN SSC Large Carnivore Initiative for Europe (LCIE) has initiated periodic reviews of the status of large carnivores in Europe and the results were published in Linnell et al. (2008), Kaczensky et al. (2013) and Chapron et al. (2014), respectively. A Regional Red List assessment for *Lynx lynx* for Europe was published in 2006 by von Arx et al. (no longer online available) in the frame of the assessment of all European mammals compiled by Temple & Terry (2007). The following information bases on a LCIE inquiry for the years 2012–2016, used for an updated Red List assessment (von Arx 2020).

Methods

In 2017/2018, a questionnaire survey was conducted for Eurasian lynx, brown bear *Ursus arctos*, wolf *Canis lupus*, wolverine *Gulo gulo*, and golden jackal *Canis aureus* among all LCIE members and additional species experts covering all Europe except Russia and Belarus. The questionnaire inquired information on abundance and distribution range, conflicts and management, as well as on threats and conservation measures for the period 2012–2016 at population and country level, respectively. The information was used to perform the European Red List assessment for the five species according to the IUCN Guidelines for the application of the Red List Criteria at regional level (IUCN 2012). In principle, a regional assessment is done like a global assessment, but if the regional population is considered to be not isolated (hence individuals are regularly immigrating), the Category is lowered by one level (e.g. Vulnerable instead of Endangered).

The distribution of the species was mapped based on their presence and frequency in each cell of the 10x10 km ETRS89-LAEA Europe grid. A cell was defined as permanently occupied if the presence of the species was confirmed in ≥3 years in the 5 years from 2012–2016 or in >50% of the time or if reproduction was confirmed within the last 3 years of the period. It was defined as sporadic (highly fluctuating presence) if the presence was confirmed in <3 years or in <50% of the time. For more information on the procedure applied for the lynx distribution mapping and area calculations see Kaczensky (2018).

Results

Status of the Eurasian lynx in Europe

The Eurasian lynx remained abundant in the northern and eastern part of its range (Fig. 1, Tab. 1). 8,000–9,000 lynx were estimated in Europe excluding Russia and Belarus. This number has been stable since the last regional assessment (von Arx et al. 2006; no longer online available). Including numbers from Russia west of the Ural Mountains according to the last global Red List assessment (Breitenmoser et al. 2015), the European population can be estimated to be 17,000–18,000 lynx, and hence the species is classified as Least Concern at the European level.

The lynx population within the Member States of the European Union remained small. With an estimated total of 7,000–8,000 individuals it is below the population size threshold for Vulnerable under Criterion C, but does currently not meet the relevant subcriteria, though. However, some of the larger subpopulations (Scandinavian and Baltic) have shown declining trends in the past decade and if this trend persists, the lynx population within the EU could meet Criterion C1 in the near future. Consequently, it is assessed as Near Threatened at the EU level.

Status of the autochthonous lynx populations

The larger autochthonous populations (Karelian, Baltic and Carpathian; Fig. 1) are still Least Concern. The Scandinavian population, however, had to be up-listed to Vulnerable due to its negative trend. The Balkan lynx *L. l. balcanicus* is Critically Endangered.

Scandinavian – Although it covers a large range (AOO over 450,000 km²), it dropped drastically in numbers to c. 1,300–1,800 individuals compared to c. 1,800–2,300 in 2011. The decline was mainly a consequence of a management decision to reduce conflicts related to sheep and semi-domestic reindeer depredation. The population would classify as Endangered under Criterion C1 (less than 2,500 mature individuals and a 20% decline over two generations). However, in 2015 and 2016, the decline stopped and there is some connectivity with the Karelian population so that single individuals are likely to disperse. The Category is therefore altered to Vulnerable. Legal hunting and illegal killing are potential threats to the Scandinavian population.

Karelian – The subpopulation in Finland further increased and was estimated c. 2,500 individuals (compared to 1,100 animals in 2004). Although there was no up-to-date information from Russian Karelia, the numbers were thought to be stable there. The Karelian population is connected to the large neighbouring population in Russia, from where a potential rescue effect is to be expected. Therefore, it was assessed as Least Concern. Potential threats: Intentional legal hunting, conflicts with hunters, lack of capacity and funding of/for management authorities.

Baltic – Counted 1,200–1,500 individuals, without considering Russia and Belarus, from where no current information was available. Although there was a slight decrease – particularly in Estonia – this population is connected both to the Karelian and the larger

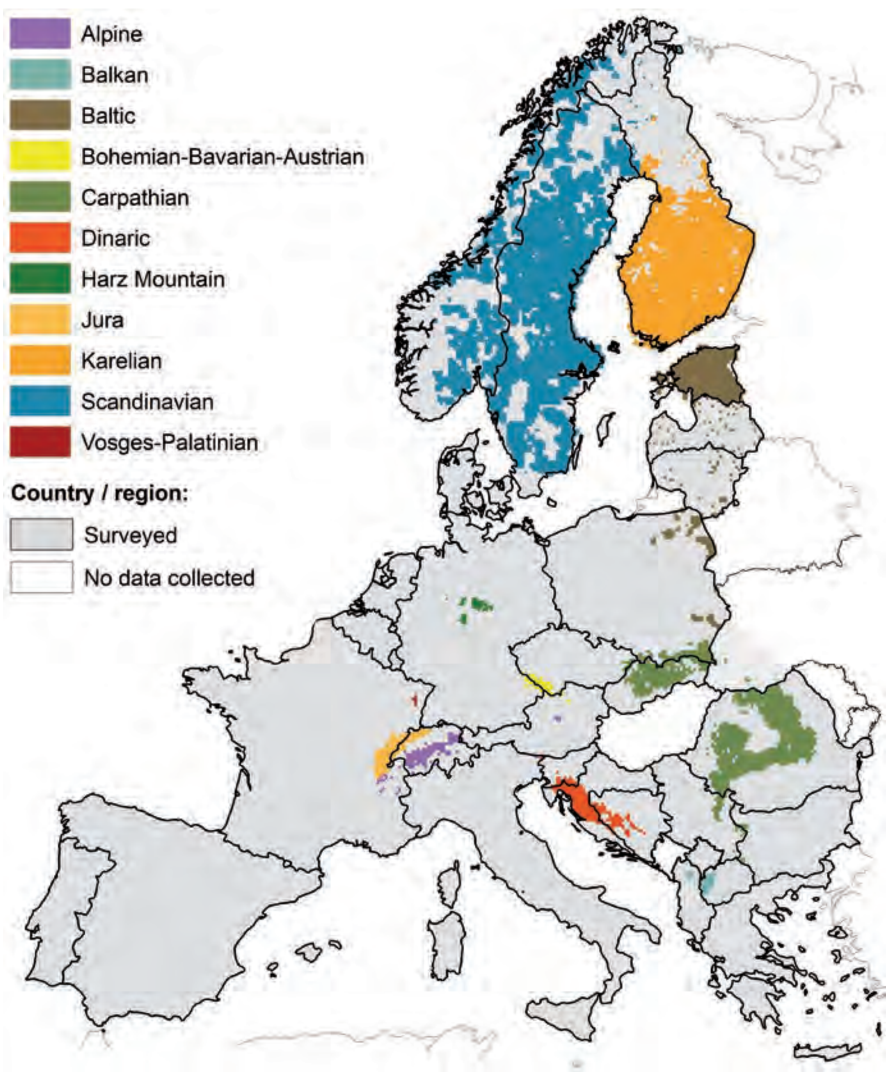

Fig. 1. Distribution of the Eurasian lynx in Europe 2012–2016. The map is showing only permantent presence. © Large Carnivore Initiative for Europe

Russian population. It is therefore assessed as Least Concern. Developments in the southern Baltic States and NE Poland need to be carefully surveyed as the distribution area in this part of the range is strongly fragmented (Fig. 1). A further reduction in Estonia has to be prevented. Potential threats: Roads and railroads, poor dialogue with stakeholders, low prey base, lack of knowledge about species numbers and trends, and lack of capacity and funding in management structures.

Carpathian – The overall number was about 2,100–2,400 individuals. It appeared to be rather stable, although in certain regions numbers have decreased, either reflecting a real trend (e.g. Ukraine, Bulgaria) or due to better monitoring systems in place, which indicate that previous numbers were overestimated (e.g. Slovakia). The population was assessed as Least Concern (Table 1), but when considering the number of mature individuals, the threshold for Near Threatened under Criterion D is almost met. A careful monitoring of the situation (which requires the implementation of better monitoring systems in many of the range countries) and a re-assessment within a few years are recommended. Potential threats: Poor integration of science into decision-making, traffic mortalities, conflicts with hunters, and lack of knowledge about species numbers and trends.

Balkan – Consists of only 20–39 mature individuals. The subspecies *L. l. balcanicus* has been assessed as Critically Endangered in 2015 (Melovski et al. 2015). Number and distribution have not changed since, and the population is isolated. Therefore, Critically Endangered under Criterion D is still valid. Major threats: Poor enforcement of legislation, lack of capacity and funding in management structures, poor integration of science into decision making, corruption, accidental illegal killing and poorly regulated large-scale forestry. In 2017, the Balkan lynx has been included in Annex II of the Bern Convention.

Status of the reintroduced lynx populations

The reintroduced populations in West and Central Europe remain small and are all classified as Endangered or Critically Endangered.

Dinaric – Numbers around 130 individuals and has decreased in the northern part of its range. Besides a high level of human caused mortality, problems of inbreeding have been noticed as a consequence of the very few founder individuals. The population is isolated and no rescue effect can be expected. It is assessed as Endangered under Criterion D. Efforts for reinforcement are on the way. Major threats: Poor enforcement of legislation (illegal killing), traffic mortalities, prey base depletion and inbreeding depression.

Bohemian-Bavarian-Austrian – Its distribution has stagnated since the late 1990s and the population decreased from c.75 individuals in 2005 to c.50 individuals in 2006–2011. There was a slight recovery to 60–80 independent individuals in 2015 and numbers seem to stabilize. 60–80 independent individuals are around 45–60 mature individuals, which is just around the threshold (50 mature individuals) for Endangered under Criterion D. Considering the previous long-term negative trend and that limiting factors have not yet been reversed, suggests however a precautionary approach and classification as Critically Endangered. Immigration from the Carpathians is unlikely as there are barriers to dispersal. Consequently, no rescue effect can be expected. Major threats: Intentional illegal killing, conflicts with hunters, and poor enforcement of legislation.

Alpine – Has slightly increased to c.163 individuals, which is however still a small number and the subpopulation remains Endangered. The increase was partly man-made due to the foundation of stepping stone subpopulations through translocations of lynx. The population lacks relevant immigration from neighbouring subpopulations which are all small or (e.g. the Carpathian population) separated through strong barriers. The Alpine population itself is fragmented into four smaller subpopulations in the Western and Eastern Alps. Consequently, the population is considered isolated and the Red List Category is not adjusted. Major threats: Illegal killing, infrastructure development (especially road constructions), vehicle and train collisions, limited dispersal, narrow genetic base (few founder animals).

Table 1. Eurasian lynx populations in Europe according to the regional Red List assessment (von Arx 2020). Label in italic indicate reintroduced populations. Trends: ↗ = increasing, → = stable, ↘ = decreasing, ↓ = strongly decreasing. RLA: IUCN Red List categories (LC = Least Concern, VU = Vulnerable, EN = Endangered, CR = Critically Endangered).

Population	Range countries	Size (ind.)	Trend	RLA
Alpine	Switzerland, Slovenia, Italy, Austria, France	163	↗	EN
Balkan	North Macedonia, Albania, Kosovo	20-39	→	CR
Baltic	Estonia, Latvia, Lithuania, Poland, Ukraine, Belarus	1200-1500	↘	LC
Bohemian-Bavarian-Austrian	Czech Republic, Germany, Austria	60-80	→	CR
Carpathian	Romania, Slovakia, Poland, Ukraine, Czech Republic, Hungary, Serbia, Bulgaria	2100-2400	→	LC
Dinaric	Slovenia, Croatia, Bosnia-Herzegovina	130	→/↘	EN
Harz	Germany	46	↗	CR
Jura	France, Switzerland	140	↗	EN
Karelian	Finland	2500	↗	LC
Scandinavian	Norway, Sweden	1300-1800	↓	VU
Vosges-Palatinian	France, Germany	1-3[a]	↓ [↗]	CR

[a] This number refers to the Vosges part only. There is an ongoing reintroduction programme in the Palatinate Forest (Idelberger et al. 2021), which was however not yet considered in the Red List assessment.

Jura – Has increased to c.140 independent individuals and the range has expanded. It however still qualifies as Endangered under Criterion D because the population size is below 250 mature individuals. In recent years, male lynx from the Jura Mts. have occasionally dispersed to neighbouring regions (e.g. Black Forest). However, there is no substantial immigration from neighbouring subpopulations, e.g. the Alps, to provide a sufficient demographic rescue effect, and the Red List Category is hence not adjusted. Major threats: Traffic accidents, illegal killing, conflicts with hunters and lack of knowledge about conflict mitigation.

Vosges-Palatinian – Numbers had dropped from 30–40 lynx in 2005 to 1–3 ten years later which is a reduction of 91% (CR Criterion C1 – 25% reduction in 4 years – in addition to Criterion D for the very small population size). There was so far too limited immigration from the Jura Mts. to provide a demographic rescue effect. Major threats were identified to be illegal killing due to conflicts with hunters, habitat fragmentation and the small population size. In the frame of the EU LIFE project "Reintroduction of lynx in the biosphere reserve Palatinian Forest" lynx have since been released into the Palatinian Forest in Germany (Idelberger et al. 2021). However, as the reintroduction only started in 2016 and there was a continuing decline throughout the years before, Critically Endangered under Criteria C and D was still considered valid by von Arx (2020).

Harz – This population was reintroduced through the release of 24 lynx between 2000 and 2006. Is was estimated at 46 independent individuals, is isolated, and qualifies for Critically Endangered under Criterion D. Road fatalities and diseases are the most relevant mortality factors for lynx in the Harz Mountains so far.

Discussion

Although the Eurasian lynx is not threatened as a species globally, continued conservation measures are required to ensure the recovery of the populations in Europe: Only 3 out of 11 populations are considered Least Concern (Tab.1). Some key conservation actions were defined by Boitani et al. (2015). Conservation efforts are particularly needed for the Critically Endangered Balkan lynx subspecies, but also for the reintroduced populations in Western and Central Europe (Alpine, Vosges-Palatinian, Jura, Bohemian-Bavarian-Austrian, Dinaric) which are still small and are classified as Endangered or Critically Endangered. These reintroductions all relied upon the Carpathians as a source population. The Carpathian population, although listed as Least Concern, seems increasingly fragmented and needs to be observed in order to not risk its capacity as parent population for the recovery of lynx in West and Central Europa. Additionally, recent negative trends in some of the larger autochthonous subpopulations (Scandinavian and Baltic) are concerning and have to be addressed.

The assessment of the populations was mainly based on total population size (number of lynx individuals) or number of independent individuals (adults and subadults, based on capture-recapture estimates by means of camera trap surveys and extrapolated to the distribution area). These are the estimates usually available from the range countries. Even within a population, the quality of information can vary greatly between different range countries. This complicates an assessment at the population level. The number of mature individuals – the unit required for a Red List assessment – is considerably lower than the total number, but also less than the numbers of independent individuals. This was considered when assessing the Red List Category. However, genetic population size was not taken into account at all, and considering the critical genetic status of some of the isolated reintroduced populations in West and Central Europe (Stiftung KORA 2021), the total size of these populations are of limited value to assess their conservation status. The disparity of data among the countries was particularly disturbing when compiling the distribution map (Kaczensky 2018). Particularly in some of the larger autochthonous transboundary populations like the Carpathian and Baltic, an improvement and harmonisation of the monitoring systems would considerably improve the picture. E.g. the SCALP Criteria (Molinari-Jobin et al. 2003, Molinari-Jobin et al. 2021) are a means to validate data from different range countries and assess the distribution and status on population level.

The data provided in the subsequent chapters of this Special Issue might differ from those presented here. The European survey and the Red List assessment base on information from 2012–2016. For some countries and populations newer data were available and considered in the following presentations.

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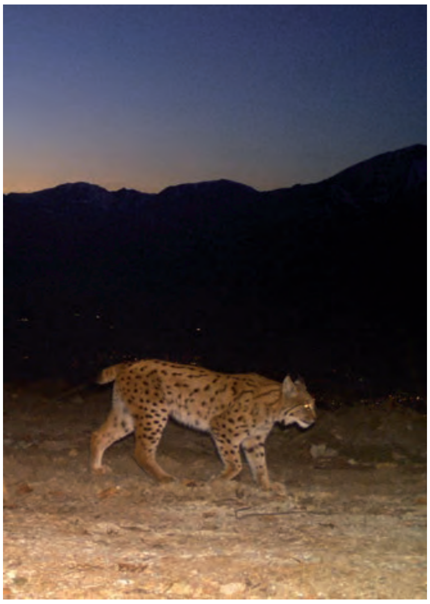

Lynx in the Alps (Photo KORA).

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Conserving the north-eastern European lowland population of Eurasian lynx

The north-eastern European lowland population of the lynx is commonly attributed to the "Baltic population" and believed to belong to the nominative subspecies *Lynx lynx lynx*. Geographically, its range extends from eastern Poland throughout the Baltic states north to Fennoscandia and east to central Asia. Within its range across north-eastern Europe the status of the species differs among the countries from fully protected year-round to a hunted species. The population is exposed to a varying degree of fragmentation with most severe habitat fragmentation in the south-western part of its range and well connected forest habitats in the north-east. The population is genetically structured, most likely as a result of habitat fragmentation. The genetically poorest subpopulation occurs in north-eastern Poland, which is most isolated from the remaining part, and the highest genetic diversity characterises the Latvian and Estonian lynx. The genomic data, however, confirm that lynx within the north-eastern European lowland population harbours a mitochondrial phylogeographic sublineage differentiated from the remaining central (Carpathian) and south-European populations, though its taxonomic value is still unclear. The lynx are facing various types of threats in different countries. Legal protection is not a sufficient measure to warrant the population's demographic security, as it is exposed either to the lack of suitable and well connected habitat, forest logging, poaching or illegal amber mining. Hunted populations may be subject to excessive quotas. The challenges of lynx conservation include restoration of the suitability and connectivity of the habitat, reintrodutions, reconsideration of hunting quotas, establishing non-invasive robust population monitoring, and increasing public awareness about the lynx conservation needs.

Distribution and population differentiation

The population of Eurasian lynx inhabiting north-eastern European lowlands extending from eastern Poland through Belarus, northern Ukraine, to the Baltic states is commonly attributed to the "Baltic population" (Von Arx et al. 2004, Boitani et al. 2015). The range of this population, however, is not clearly delimited due to lack of data from the Russian territory (Boitani et al. 2015). It should be assumed that it extends towards the east including large areas of continuous forest covering western Russia. On the other hand, the "Baltic population" of lynx probably should not include animals from the area of Karelia and Finland, because the Gulf of Finland plays some role as a barrier for gene flow (Ratkiewicz et al. 2014). They are believed to belong to the nominative subspecies *Lynx lynx lynx* (Kitchener et al. 2017).

The population distribution is very irregular because it consists of a severely fragmented section in the south-western part of the range (on the territory of Poland, Belarus, Ukraine, the Kaliningrad Oblast and Lithuania) and a large, continuous part of the range in the north-east (Latvia, Estonia and Russia). The distribution of lynx largely coincides with the extent of fragmentation of forest habitat, and the most isolated populations are disseminated across the most fragmented habitat at the south-western edge of the species range (Fig. 1).

The population is clearly genetically structured, most likely as a result of long-term habitat fragmentation and isolation. Diversity of both, microsatellite and mitochondrial markers showed highest differentiation between the lynx from north-eastern Poland (particularly the Białowieża Forest) and all remaining subpopulations within the "Baltic population" (Ratkiewicz et al. 2014). The most isolated population of north-eastern Poland is also genetically the poorest, whereas the Latvian and Estonian lynx harbour highest genetic diversity. There is a very limited gene flow between the lynx of north-eastern Poland and the remaining "Baltic population". Most effective gene flow was detected between Finnish and Russian (Kirov Oblast) lynx and least between the Russian and Estonian animals (Ratkiewicz et al. 2014), indicating that the Finnish population should not be included within the "Baltic population" of this felid. There was also very weak (unidirectional) gene flow from Baltic (Estonia) to Finnish lynx, which suggests that the Baltic population should receive most gene flow from unsampled Russian lynx or only occasionally indirectly from Finland. The genomic (nuclear intergenic autosomal and mitogenomic) data confirmed that lynx within the north-eastern European lowland population cluster with Russian lynx up to the Ural Mountains, but also harbour a mitochondrial phylogeographic sublineage differentiated from the northern (Scandinavian) and south-European (Balkan) populations (Lucena-Perez et al., 2020). However, the taxonomic value of this finding is still unclear.

Population status and threats

The status of the species varies dramatically among the countries harbouring the Baltic lynx population. It is fully protected year-round in Poland, Lithuania, Belarus and Ukraine with high fines imposed for killing individuals, but in contrast, it constitutes a legally hunted species in Estonia, Latvia and large parts of Russia. Legal protection, however, is not a sufficient measure to warrant the population's demographic security. The lynx are facing various types of threats within their range across north-eastern Europe. Factors contributing to population threats in countries ensuring the species full legal protection include the lack of suitable and well-connected habitat, small population size, low prey availability, forest logging, poaching or even illegal amber mining. Hunted populations may be subject to the risk of unsustainable quotas.

Poland

Conservation status of the species is least favourable in Poland. Despite being a large, relatively well forested country (30% of the area), the area occupied by lynx accounts for only 3.5% of the entire territory (Schmidt 2011). Although the lynx has been fully protected since 1995, its range has not increased and numbers remaint at a level of 200 individuals (Mysłajek et al. 2019). Habitat suitability modelling showed that the current distribution of lynx largely overlaps with the major patches of best quality habitat – localised in north and south-eastern Poland – in terms of structure and diversity of forests (Schmidt & Górny, in prep.). However, considering the general availability of sufficiently large patches of forest cover, there would be a potential to expand the population range of this felid nearly three-fold so that it could occur in 10% of the country's area. It is thus likely that habitat fragmentation along with its poor quality (simplified structure of forest monocultures) is obstructing the lynx population expansion within Poland. Another issue that may negatively affect the development potential of the lynx population is low availability of the main species of lynx prey – the roe deer, a fact that has been established within the framework of a large-scale monitoring of ungulates in Poland (Borkowski 2019).

Within the Polish part of the lynx range there are thus five major conservation challenges, which include: (1) restoring and improving the connectivity between large forest complexes; (2) improving the habitat quality in the forests; (3) improving the availability of the food resources for lynx; (4) strengthening and increasing the existing population through reintroductions or reinforcements; and (5) implementing the state-wide monitoring of large carnivores.

Lithuania

The lynx population in Lithuania has been fully protected since 1975, though during recent decades, it has experienced a decline from 200 to 30–40 individuals in 2010 (Balčiauskas 2021). The population is currently distributed throughout the country, although it is severely fragmented due to the very sparse distribution of forest habitats. However, as an effect of a successful reintroduction programme conducted in 2011–2017, as well as implementation of measures directed at improving breeding habitats and prey availability, the lynx population has started to increase since 2015. A higher frequency of recorded family groups has been observed (Balčiauskas et al. 2017). The population size is currently estimated at approximately 150 individuals (L. Balčiauskas, pers. comm.). Habitat fragmentation and lack of primary habitats suitable for lynx breeding are being considered as important challenges for effective conservation of the species. Competitive interactions with wolves are also regarded as an interfering factor.

Latvia

The population of lynx in Latvia has a favourable status. Therefore, based on the detailed conservation strategy, a limited use of the species for hunting purposes is allowed in accordance with Article 16 of the EC Directive 92/43/EEC (Habitats Directive) on the Conservation of Natural Habitats and of Wild Fauna and Flora. Hunting however is banned in the middle part of the country. The population has been growing steadily since the late 1960s and early 1970s. Its distribution covers the whole area of the country and recent estimations suggest a population size of 600–1600 individuals, depending on the survey method applied (Ozoliņš et al. 2017). Some 100–160 lynx are harvested annually, half of the killed animals being used for research purposes such as population demography, genetics and parasitology. Although the lynx status is monitored and the harvest of the population seems to be well controlled, there is concern that a lack of coordination in management action plans (including its dual supervision by two Ministries – Environment and Agriculture) may cause future conservation problems for the species. As the replacement of traditional agriculture with new land uses, such as deer farming or free-ranging sheep husbandry, has recently been promoted, there are claims rising for lynx depredation on livestock. Establishing ecological corridors to mitigate the effects of developing road infrastructure and restrictions on hunting to ensure that conservation status is maintained are among the major challenges in lynx conservation in Latvia.

Estonia

Estonia is the only EU country where the lynx is a species derogated to the Annex V of the Habitats Directive. It is a species hunted from December to February with a strictly quoted bag. According to the Large Carnivore Action Plan, the population size of lynx is expected to be 100–130 reproducing females (Männil & Kont 2013). The current population status is, however, unfavourable with 50–65 reproductive females recorded in 2013–2018. Several factors could have contributed to the population decline, including the crash of roe deer numbers due to extremely harsh winters in 2010/2011, too high harvest quotas from 2012–2015, illegal hunting, sarcoptic mange and emigration (in search for areas with better prey base; Veeroja & Männil 2019). Contrary to demographic model predictions, the lynx population has not improved by 2018, although the roe deer population has recovered well. In response to the population decline, hunting quotas have been suspended from 2016 to 2019.

Ukraine

The Baltic population of lynx occurs only along the northern border of the country in the Polesie region and it is estimated at 60–80 individuals (M. Shkvyria, unpubl. data). It is likely a continuous population with lynx in Belarus and the Russian Federation. The species is fully protected in the country and included in the Red Book of Ukraine. Main conservation challenges for the species include establishing a conservation action plan and state-wide monitoring. The lynx is threatened by massive forest logging, poaching, illegal capture for captive breeding as pets, and illegal amber mining,

Belarus

The species has been protected since 1981 and it was included in the Red Book of Belarus in 1993. Its distribution is fragmented throughout the country and the official estimation of lyxn numbers varied from 250 to 830 individuals during the period 2000 to 2018 (A. Kozorez, pers. comm.). However, these numbers have never been achieved by rigorous state-wide monitoring. In 2011, the Lynx Population Management Plan was approved for a period of 10 years. Measures have been initiated to update the status of the lynx, as well as attempts to estimate its population size. Although the removal of the lynx from the Red Book has recently been suggested, this seems unlikely at the moment, but instead, some licensed hunting might be considered (A. Kozorez, pers. comm.). Currently, the main threat to the lynx in Belarus is poaching due to widespread belief that it has harmful effects on the populations of ungulates.

Russian Federation

The Eurasian lynx is considered a widely distributed and common species in the Russian Federation. Therefore, it is hunted in the majority of the Russian territory. However, within the European part of Russia its status has recently shifted from hunted to protected in 23 out of 46 regions (Lissovsky et al. 2019). Programmes of reintroduction have been also recently proposed (A. P. Saveljev, pers. comm.).

Common challenges for the north-eastern populations

The status and distribution of lynx in particular countries across the Baltic population are highly diverse from strictly protected and threatened by anthropogenic factors to hunted populations that are increasing in numbers. Moreover, there is a significant genetic differentiation and differences in genetic variability among the sub-populations resulting from recent anthropogenic impacts. Considering the whole range of the north-eastern European lowland population of Eurasian lynx, the major common challenges of species conservation include restoration of the suitability and connectivity of the habitat, improving prey availability, establishing a unified monitoring system and improving public awareness about lynx ecology and conservation neeeds. The individual sub-populations require additional specific conservation measures, such as reconsideration of hunting quotas, mitigation of conflicts caused by livestock depredation, or improvement of habitat quality.

Fig. 1. Distribution of the Eurasian lynx (grey) in central and north-central Europe. Modified from von Arx et al. (2004); forest cover=green, dashed line=reintroduced populations..

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Conservation needs of the Carpathian lynx population

The population of Eurasian lynx in the Carpathian Mountains is one of the largest in Europe, with a total population size of ~2,100–2,400 individuals. However, the status of the species in the Carpathians was based solely on "expert opinions", while relevant scientific data were restricted. Recent research indicated that these figures are not reliable and strongly overestimate the population size. Exaggerated data and misleading information on the status and trend of the lynx population have fostered conflicts between the lynx and human interests, and ultimately leading to illegal killings. Negative attitude of hunters towards lynx originates in a belief that the predator is responsible for the alleged decrease of roe deer populations in Slovakia. Moreover, illegal killing could have some synergetic effect with the development of traffic infrastructure, which increasingly disrupts the connectivity between suitable habitats and exacerbates human-induced mortality. Carpathian Mts. have been and still are a source for lynx reintroduction and reinforcement projects and are of great importance for the large-scale conservation of lynx in Europe. Authorities in charge, lynx experts and interested groups from the Carpathians should jointly establish a standardised robust population monitoring and seriously mitigate anthropogenic factors jeopardising lynx survival. A sound cooperation between all countries sharing the Carpathian population for the conservation and management of the lynx is required. We recommend in particular the adoption of a jointly developed Pan-Carpathian conservation and management strategy and related national action plans.

Current status of the Carpathian lynx population

Covering an area of 209,256 km², the Carpathian Mountains extend over eight European countries, from Romania and Serbia in the south through the Ukraine, Poland, Slovakia and Hungary to the Czech Republic and Austria in the north (Fig. 1). The region provides home to 16–18 million people, living in many different environments, from traditional villages to urban centres. Forest cover is distributed unequally from 29.5% in the Hungarian part to almost 60% in Romania; less than a third of the Carpathians are covered by open semi-natural habitats, predominantly grassland. From the Würm/Weichsel Glaciation (150k–15k bp) the Carpathians were a forest refugee most likely, already inhabited by the lynx that we today consider to be *Lynx lynx carpathicus*, a subspecies that obviously did not expand after the end of the Ice Age and therefor is still distinct from other lynx forms in Europe (Breitenmoser & Breitenmoser-Würsten 2008).

The autochthonous lynx population covers at present the north-western and southern part of the mountain chain of the Carpathians, and has recently expanded in the south into Serbia and Bulgaria; it however seems to be sparsely present in the Ukraine (Fig. 1). The share of the population among the countries corresponds almost to the respective share of the Carpathian region (Table1), with exception of the Ukraine and Bulgaria, where the present distribution is not known. Most of the Carpathian population is situated within Romania and Slovakia (Fig. 1), which have therefore a special responsibility for the conservation of the entire population (von Arx et al. 2004, Kaczensky et al. 2013, Boitani et al. 2015, von Arx 2018). In all Carpathian countries, lynx is fully protected by law (Table 2). The population is considered to be one of the largest in Europe, with a total population size of ~2,100–2,400 lynx according to the population assessment for 2012–2016 (von Arx 2018). The Carpathian population appears to be stable, although in certain regions, numbers have decreased, either reflecting a real trend (e.g. Ukraine and Bulgaria) or due to more reliable monitoring (Table 3; von Arx 2018). The status of the species in the Carpathians was based solely on "expert opinions", while relevant scientific data were limited or absent. Scientific robust monitoring in Slovakia has recently demonstrated that such data are not reliable and are overestimating the population size (Kubala et al. 2019, Duľa et al. 2021). Nevertheless, this situation has not been addressed for a long time by the state administration and consequently led to the presentation of vague and misleading information regarding the status and population trend at local and national levels (Smolko et al. 2018, Kubala et al. 2019).

Table 1. Extension and distribution of lynx in the countries sharing the Carpathian population. Information from Hungary are poor, but there is an expansion in the north, along the border with Slovakia. The distribution in Ukraine and Bulgaria is presently unknown. In Bulgaria, confirmed observations (camera trapping) were available from the Osogovo Mountains till the end of 2015. Subsequently, in spite of intensive camera trapping, there were no records.

Country	Lynx extension and distribution area (km²)		
	Constantly occupied area	Single observation confirmed	Total
Romania	66,000	unknown	unknown
Slovakia	27,200	890	28,090
Poland	10,100	1,100	11,200
Ukraine	unknown	unknown	unknown
Czechia	1,200	800	2,000
Hungary	2,100	100	2,200
Serbia	3,000	5,000	8,000
Bulgaria	unknown	unknown	unknown

Conservation challenges

The lack of a scientific basis when reporting and interpreting data on lynx population leads to conflicts between the lynx and human interests such and fosters illegal killing (Table 4; Červený et al. 2002, 2019, Zlatanová et al. 2001, Duľa et al. 2021). Negative attitude of local hunters towards lynx originates in a belief that the species is responsible for the alleged decrease of roe deer *Capreolus capreolus* populations in Slovakia (Smolko et al. 2018). However, it has been ignored that apart from lynx as its main predator, roe deer population is also affected by competition from rapidly growing red deer *Cervus elaphus* population, which results in decreased fitness of both adults and juveniles (Latham 1999, Richard et al. 2010). The influence of other species on roe deer fawns, such as highly abundant red foxes *Vulpes vulpes*, wild boars *Sus scrofa* and a poor management of agricultural land is being overlooked as well (Smolko et al. 2018). Although factors behind illegal killing may differ according to the local socioeconomic situation, it may result in significant annual mortality in the lynx population. For example, it was estimated to account for at least 20% of the adults in Czechia (Červený et al. 2019) and up to 22% in the Białowieża Forest in Poland (Kowalczyk et al. 2015), and there is no reason to expect that Slovakia might be different (Kubala et al. 2020, Duľa et al. 2021).

Moreover, illegal killing can have a synergetic effect with habitat fragmentation (Table 4; Kubala et al. 2020): At large scale, loss of habitat quality and connectivity and decrease of prey availability (enhancing conflicts with hunters), could seriously jeopardise the viability of the lynx population, especially in the Ukrainian Carpathians (von Arx 2018). At small scale, as the traffic infrastructure development is expected to disrupt connectivity between suitable habitat patches and increase human-induced mortality (Huck et al. 2010, Kubala et al. 2019, 2020, Duľa et al. 2021). The expansion of road infrastructure menaces the long-term viability of lynx in Europe by restricting migration movements between and within mountain ranges (subpopulations) and increasing the risk of collisions with vehicles (von Arx et al. 2004, Kaczensky et al. 2013, Boitani et al. 2015). The development of transport networks is a high priority in all Carpathian countries as considered immensely important for the economy of the region. As a consequence, the creation of barriers and the interruption of important migration routes may result in limited gene flow and isolation of subpopulations (von Arx et al. 2004, Krojerová-Prokešová et al. 2019, Kubala et al. 2020). If the lynx range in the Ukraine is broken (Fig. 1; von Arx 2018), it is a potentially dangerous gap in the continuous distribution in the Carpathians and threatens the long-term (genetic) viability of the entire population.

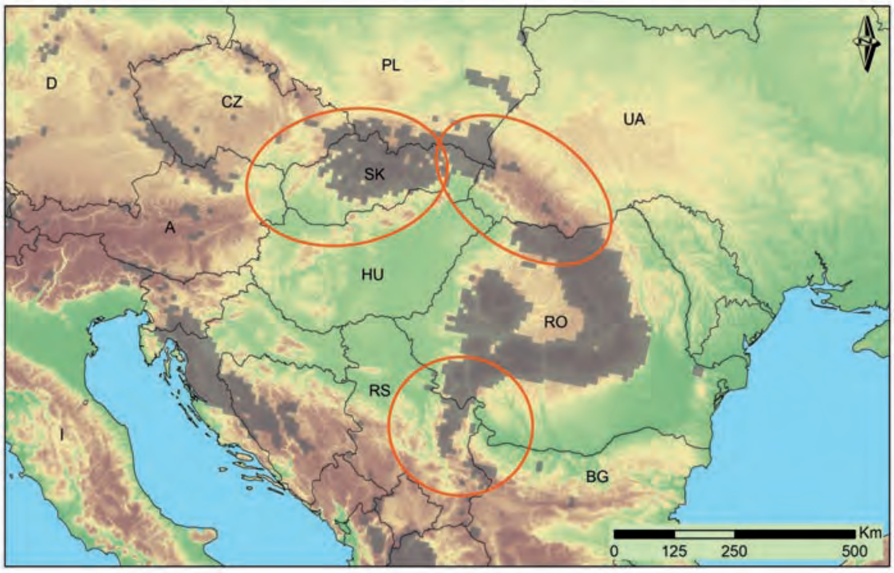

Fig. 1. Eurasian lynx distribution in the Carpathian Mountains according to the population assessment for 2012–2016 (grey shaded; von Arx 2018). Red polygons represent regions for which the necessary conservation measures and actions must be implemented as a matter of priority: the Ukrainian Eastern Carpathians and especially the border areas with Romania, Slovakia and Poland, area of the core and marginal parts of the Slovak lynx population and its natural dispersion towards northern Hungary, western Austria and northern resp. southern Czechia, as well as the regions with a natural expansion of the Romanian lynx population in the Serbian Carpathians and Bulgaria.

Conservation actions and measures

A sound cooperation between all countries sharing the Carpathian population for the conservation and management of the lynx is required. To identify and implement most important conservation actions and measures, we recommend in particular the adoption of a jointly developed Pan-Carpathian conservation and management strategy and related national action plans. The overall trend of the Carpathian lynx population is assumed to be stable or slightly decreasing (Table 3;

Table 2. Conservation and management status of the lynx in the Carpathian countries. No Management plan is to be expected for Bulgaria within the next 5 years. [A] Conservation, Action or Management Plan, [B] implementation of Management plans in Slovakia, Czechia and Serbia is in progress.

	Management		
Country	**Legal status**	**Planning [A] status 2011**	**Planning [A] status 2019**
Romania	fully protected	none	none
Slovakia	fully protected	none	Management plan [B]
Poland	fully protected	none	none
Ukraine	fully protected	none	none
Czechia	fully protected	none	none
Hungary	fully protected	Conservation plan ended in 2011	no actual plan, revision is planned
Serbia	fully protected	Management plan [B]	Management plan [B]
Bulgaria	fully protected	none	none

Table 3. Lynx population size and trend in the Carpathian Mountains during the years 2011-2019. Density in number of lynx/100 km². [A] for suitable lynx habitat. [B] Pirga et al. 2018: Bieszczady (Eastern Polish Carpathians), density only for adult individuals. [C] Pirga et al. 2018: Bieszczady (Eastern Polish Carpathians), density adults and juveniles.

Country	Estimation 2019	Density	Trend 2001–2011	Trend 2011–2019
Romania	not available	unknown	→	→
Slovakia	250–400	0.96 [A]	likely ↗	→/↘
Poland	no reliable data	1.3 [B]–2.4 [C]	unknown	unknown
Ukraine	336	unknown	unknown	unknown
Czechia	10–12	0.70 [A]	→/↘	→/↘
Hungary	12–20	0.68	stable	→/ likely↗
Serbia	40–60	1	↗	→/slightly ↗
Bulgaria	unknown	unknown	likely ↗	likely ↘

von Arx 2018). However, this assessment is not based on robust data and the actual tendency is therefore difficult to judge (Kubala et al. 2019, Duľa et al. 2021). This stresses the need for more accurate information and the adoption of a standardised monitoring system based on a spatial concept and scientific robust methods applicable in each country by the national wildlife management and including the hunters' and foresters' organisations. It is also necessary to establish a programme to mitigate the effect of conflict between lynx and local communities and stakeholders (especially hunters) in order to reduce illegal killing. Threats, such as habitat loss or fragmentation and the development of traffic infrastructure must be assessed and mitigated. All future development projects must be carefully designed to avoid negative impacts on the Carpathian lynx and other wildlife populations. Environmental Impact Assessment (EIA) procedures must be strictly carried out for transport network projects in the whole region.

These important conservation actions and measures are in accordance with the Action Plan for the Conservation of the Eurasian lynx in Europe (Breitenmoser et al. 2000, von Arx et al. 2004), the Key Actions for Large Carnivores in Europe (Boitani et al. 2015) and the International Action Plan on Conservation of Large Carnivores and Ensuring Ecological Connectivity in the Carpathians, compiled by the Convention on the Protection and Sustainable Development of the Carpathians (Papp et al. 2020). The Carpathian Convention is supporting a preparation and compilation of standardised monitoring guidelines for lynx in the Carpathians as well as joint development of a Pan-Carpathian conservation and management strategy for the lynx as a blueprint for more concrete national action plans.

The Carpathians have been and still are a source for lynx reintroduction and reinforcement projects (Breitenmoser & Breitenmoser-Würsten 2008; Bonn Lynx Expert Group 2021) and have a great importance for the international management and large-scale conservation of lynx in Europe. Therefore, to a large extent, the conservation of lynx in western and central Europe depends on the status of the Carpathian lynx population (von Arx et al. 2004, Kaczensky et al. 2013, Boitani et al. 2015). Paradoxically, the reintroduced Carpathian lynx populations are today better surveyed and studied than the autochthonous source population (see various contributions in this Issue). Thus, there is a general need to improve the basic knowledge on the lynx population status and biology as well as on human attitudes in this region (Boitani et al. 2015, Kubala et al. 2019). It would be good to demonstrate the positive economic benefits available from large carnivores, for example through eco-tourism. Obviously, it is not enough to simply put the lynx under legal protection without further interacting with stakeholders or mitigating threats. Only a range-wide cooperation with an efficient adaptive approach can ensure the long-term and large-scale survival of the species at the geographic scope of the Carpathians and hence contribute to the conservation of both, the autochthonous and reintroduced populations (von Arx et al. 2004, Kaczensky et al. 2013, Boitani et al. 2015, Bonn Lynx Expert Group 2021).

Table 4. Summary of lynx harvest and known losses, including illegal killings and other mortality in the Carpathian Mountains during the period 2011–2019. [a] 2001–2014. [b] vehicle collisions 2011–2016. [c] 2001–2018, other mortality: vehicle collisions 5, unknown 2. [d] 2012–2018. [e] vehicle collisions 2012–2018.

	Harvest and known loses			
Country	Harvest number	Illegal killings	Other mortality	Total 2011-2019
Romania	6	2[d]	3[e]	11
Slovakia	0	7[a]	17[b]	24
Poland	0	unknown	unknown	unknown
Ukraine	unknown	3[a]	unknown	unknown
Czechia	0	2	3[c]	5
Hungary	0	unknown	unknown	unknown
Serbia	0	unknown	unknown	unknown
Bulgaria	0	≥ 2 confirmed	unknown	3

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Male Beňadik pictured in Slovakia. It was later captured and included into the telemetry monitoring survey (Photo B. Machciník).

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Balkan lynx and the Balkan Lynx Recovery Programme

The Balkan lynx *Lynx lynx balcanicus* is a subspecies of the Eurasian lynx distributed in the south-west Balkans, with relict populations in the Mavrovo National Park and surroundings in North Macedonia and the Munella Mountains in Albania, and with single individuals in Bjeshkët e Nemuna, western Kosovo. In 2015 the Balkan lynx was assessed as Critically Endangered in the IUCN Red List. Main threats involve small population size, limited prey base, habitat degradation, and poaching. The assessment was done on the basis of 10 years of lynx research and monitoring in the range countries through the Balkan Lynx Recovery Programme. This transboundary project strives to (1) create capacities for a long-term conservation project, (2) monitor and study the extant population, (3) understand local people's attitudes towards lynx and other large carnivores, and engage them in conservation efforts, and (4) establish a protected-area system for the benefit of the Balkan lynx and its prey. The ongoing project is focusing on diminishing the main threats to the Balkan lynx and engaging with stakeholders and local people with regard to awareness raising, knowledge gathering, improving conservation policies, and site protection.

Based on the number of mature individuals as revealed from 10 years of monitoring and research, the Balkan lynx, a subspecies of the Eurasian lynx, was assessed as Critically Endangered in the IUCN Red List of Threatened Species (Melovski et al. 2015). Historically, the population once spread through the whole peninsula (Mirić 1981), but the major eradication of large carnivores in the continent (Breitenmoser 1998) took a toll on the Balkan lynx as well. Mirić (1981) suggested a possible bottleneck of the population even before World War II, estimating merely 15 to 20 mature individuals. By then, the Balkan lynx had already disappeared from most of the Balkan countries and its presence was restricted to the south-western part (Fig. 1). The population gradually started to recover due to the protection status granted in 1949 and the series of protected areas declared in former Yugoslavia in the early 1950s. It ultimately reached 280 individuals by 1970s (Mirić 1981). The second decline begun at the end of the 20th century, when civil unrest in the countries of south-west Balkans led to a major decline in prey species, massive poaching of (protected) game and large-scale deforestation (Breitenmoser et al. 2000, Melovski 2013).

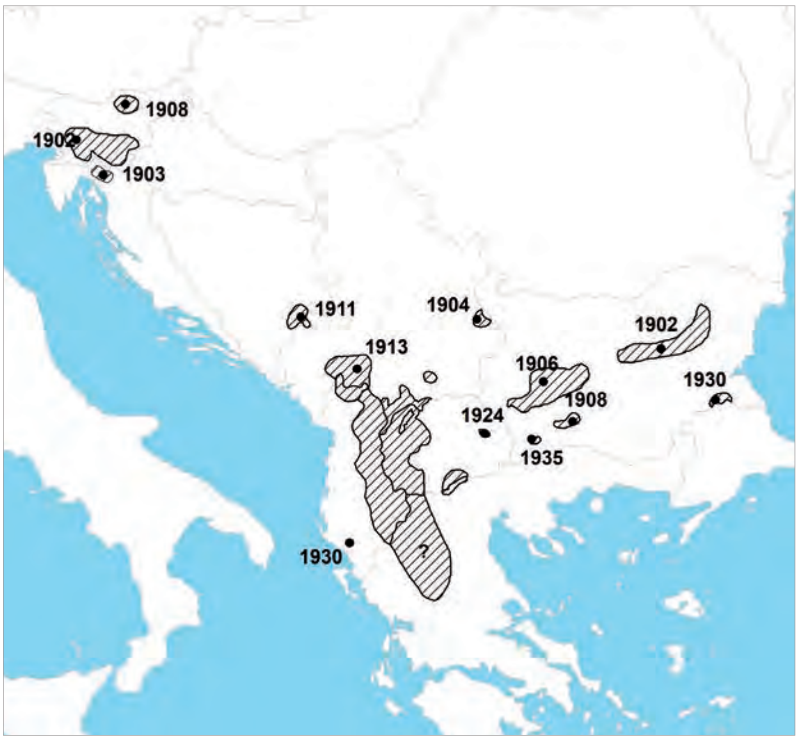

Fig. 1. Distribution of the Balkan lynx at the end of the 19th and the first half of the 20th century. The years represent last lynx sightings in the respective areas. The data for the map were derived from Mirić (1981).

The Balkan lynx has been subject of conservation concerns already in the 1960s (Kratochvil 1968). Subsequent status reports confirmed the need for action highlighting the isolation, decline and possible uniqueness of the population (Breitenmoser & Breitenmoser-Würsten 1990, Breitenmoser-Würsten & Breitenmoser 2001). It was not until 2005, when first activities for the lynx in the range countries took place, with two NGOs from Albania and Macedonia engaging in a conservation programme with support from German and Swiss partners. This initiative, supported by the MAVA Foundation and known as the Balkan Lynx Recovery Programme (BLRP; Breitenmoser et al. 2008), became one of the longest continuous conservation projects in the region. BLRP strives to create capacities both at the governmental and nongovernmental sectors, educate children in the distribution range of the Balkan lynx, monitor the population continuously and systematically, conduct basic ecological research, enlarge the protected area system relevant for lynx survival, lobby for better policy and legislation, collaborate with relevant stakeholders (particularly hunters), and build a network of interested local people in the range countries. In this article we reflect on the main achievements of the programme, emphasize the challenges and threats the Balkan lynx population is facing, and, propose solutions and mitigation measures.

Achievements 2005–2020

The main task of the newly formed Balkan lynx teams in Albania and North Macedonia were to first find evidence for the existence of the Balkan lynx and to map its distribution. For this reason, a systematic questionnaire survey was organised targeting local people with topical backgrounds (hunters, foresters, etc.) to obtain information on lynx distribution, trend, and possible conflicts with people (Melovski et al. 2013). This baseline survey, conducted in 2006–2007 in Albania and Macedonia, and 2013 in Kosovo and Montenegro outlined the up-to-date distribution range of the Balkan lynx and revealed the most important areas for conservation and further research (Melovski et al. 2018; Fig. 2). The results from the baseline survey clearly indicated Mavrovo National Park in Macedonia as the core area for the Balkan lynx (Fig. 2). In 2008, we conducted the first systematic camera-trapping survey in the National Park. The survey was repeated in 2010, 2013, 2015 and 2018 and gave robust estimates of lynx population density and trend in the core zone. Similar research was done in Munella Mountains (Fig. 2), which came into focus only in 2011, with the first evidences of Balkan lynx from Albania by means of camera-trapping. Over the subsequent years, Munella was found to be the second core area of the Balkan lynx, a small nucleus of 4–6 individuals and the only area with confirmed reproduction outside Mavrovo (Koçi et al. 2017). Continuous camera-trapping efforts from 2013 to 2020 did not succeed in picturing any lynx in Montenegro although the colleagues from Kosovo managed to photograph at least two different individuals in Bjeshkët e Nemuna National Park in western Kosovo (Fig. 2). This was, however, the only lynx presence detected in Kosovo so far. Furthermore, lynx presence was detected in other areas close to the core area – Shebenik NP and Shara Planina. Their significance is three-fold: they contribute to the transboundary-protected area system which is relevant for the Balkan lynx, act as bio-corridors for further spread of the population, and, most importantly, they further add to the suitable habitat that can host new lynx individuals (Fig. 2).

Eleven years of radio-telemetry research in Macedonia resulted in twelve radio-collared lynx (7 males and 5 females) and provided the first information on the spatial requirements of the Balkan lynx. It revealed that its land-tenure system is similar to the lynx from Western and Central Europe (Melovski et al. 2020). Diet-wise, again, similarly to the other European populations, Balkan lynx feed mainly on ungulates (roe deer Capreolus capreolus and chamois Rupicapra rupicapra) with 75% (n=167) of the documented prey (n=222) belonging to this group of mammals (Melovski et al. 2020).

The monitoring and research in the core areas would not have been possible without collaboration with the authorities (park officials or representatives from the regional agencies for protected areas). Moreover, the BLRP team increasingly counts on the support from interest groups such as hunters, game wardens, foresters, veterinarians, and journalists and tries to engage them into the day-to-day conservation activities. The results of these collaborations are encouraging and consist of help in the field, promotion, awareness raising, veterinary assistance and more (Melovski et al. 2021).

Challenges and threats

Although strictly protected in the range countries, the Balkan lynx in the modern time is facing threats that involve unsustainable prey harvest, poaching and infrastructural development. The prey depletion is due to illegal harvest, old-fashion hunting systems that lack modern monitoring schemes, but also motivation and means to curb illegal activities inside the hunting grounds. Lynx poaching is not so prominent in the range countries. However, given the threatened status of the population, every lost individual affects the population to a large extent.

Another challenge is the influx of stray dogs. The project documented on several occasions the massive incursion of stray dogs in the area of interest as well as the impact that dogs have by scavenging prey remains of Balkan lynx and by competing for the same food (roe deer, for instance).

Less developed industrial base and low Human Development Index defines the countries in south-western Balkans as developing countries (O'Sullivan & Sheffrin 2003). Much effort is placed on the infrastructure development which, among other things, includes modernised road network, energy and tourist infrastructure. Because boosting the local and national economy is the main focus, less emphasize is placed on the mitigation measures and the negative aspect these economic and social merits bring to the wildlife. This can have a negative effect on the Balkan lynx population by further fragmenting their limited suitable habitats.

When it comes to cooperation with relevant institutions, the Balkan lynx team has experienced both, favourable and unreceptive relationship, owing much to the polarised political climate that has been in place for the past 15 years in the range countries, leading to temporal expelling of the BLRP team from Mavrovo NP on several occasions from 2012 until 2017. The unfavourable climate for nature conservation also hampered the declarations of further protected areas in Macedonia (Melovski et al. 2021). In Albania and Kosovo, however, several protected areas have been declared between 2008 and 2013, mainly for protecting the Balkan lynx (Shumka & Trajçe 2012). However, the Munella Mountains as second most important stronghold of the Balkan lynx, still lacks any protection status due to deficient engagement from the government. The oscillating politics in the south-western Balkan countries are not only unpredictable, but obstructs long-term planning as there is no lasting commitment and reliable policy.

Solutions

Density estimation in Mavrovo National Park and its surroundings showed indications for a slight increase over the period of one decade. However, the preliminary results of the 2021 camera-trapping session indicate decrease in the population size in this most important area of the Balkan lynx. This calls for closer monitoring in the Mavrovo National Park area by means of density estimation as well as genetic monitoring. Stochastic events can have a strong impact on small and isolated populations, and possible inbreeding depression might have severe consequences on this critically endangered felid by reducing its reproductive potential. Systematic genetic monitoring should become a general practice in the next decade. For this reason, good connectivity between the subpopulations of Mavrovo and Munella have to be secured. Additionally, the spread of new individuals in new areas requires good connectivity to suitable habitats beyond the current distribution range (Ivanov 2014). We believe that achieving this requires wildlife-friendly infrastructure development, more intensive engagement with local people, and awareness raising at all levels, hopefully leading to an earnest commitment of the authorities. Moreover, research and monitoring in the range countries should continue in order to carefully observe the population developments and assess the effect of conservation measures. Political work should take advantage of beneficial opportunities. Albania, Kosovo and North Macedonia are aspiring countries to join the EU and the hope is that the stricter EU policies on nature conservation will bring directives and consistency into environmental issues. A lot of the policy work in the project will have to be di-

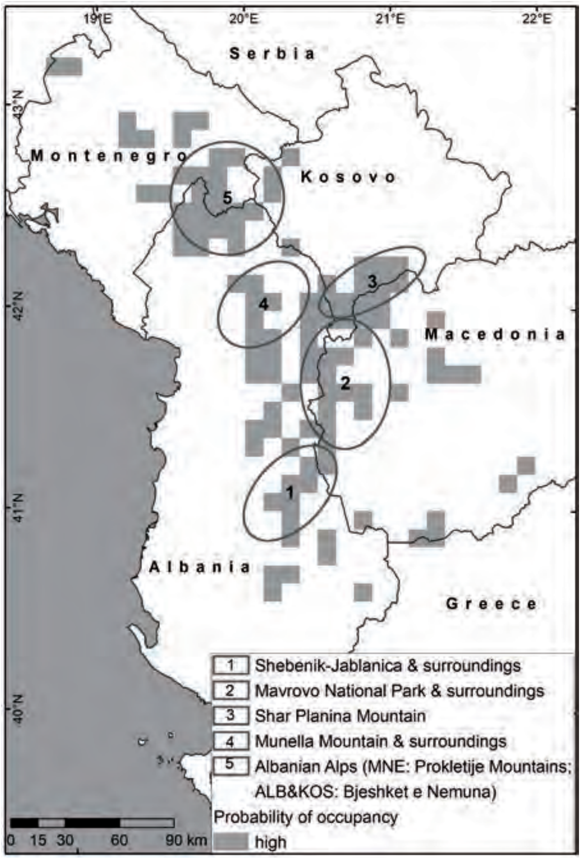

Fig. 2. Five important areas for the conservation of the Balkan lynx, identified based on high probability of occupancy (Melovski et al. 2018).

rected to mitigating the damage that the new highways might pose to the Balkan lynx and its prey. This includes the obligation of the governments to designate key areas for Balkan lynx protection with effective management bodies, but also, change of legal acts in the hunting and forestry sectors that threaten the survival of the Balkan lynx and strengthen the law enforcement. An updated IUCN Red List assessment should further shed light on the status of the population and this implies continuous monitoring and research to fill the missing gaps in Balkan lynx demographics, social status, spatial and movement ecology. Lastly, educating young people in the rural, mountain areas in the Balkan lynx distribution range, is a step forward for addressing unsustainable wildlife offtake while emphasizing sustainable, rural tourism. In parallel, the cooperation with local hunting groups needs to continue in order to engage local hunters in regular monitoring activities of wildlife. Local people are true assets for a continued and long-term conservation programme.

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Conservation challenges in the Bohemian-Bavarian-Austrian lynx population

The development of transboundary cooperation in monitoring and conservation of the Bohemian-Bavarian-Austrian lynx *Lynx lynx* population is presented. From 2013–2020 two international lynx projects, co-financed by the EU, established monitoring standards and collected comprehensive demographic and genetic data on population level. Main threats for the population are illegal killing and inbreeding.

The Bohemian-Bavarian-Austrian BBA lynx population stretches over three countries, the Czech Republic, Germany and Austria. This region forms one of the biggest cohesive woodland areas of Central Europe. Two national parks at the Czech-German border (Šumava and Bayerischer Wald) encompass 680 km^2 and 240 km^2, respectively. They are surrounded by large cultural and landscape protection areas with diverse land cover and land use practices. Economical income mainly stems from forestry, agriculture and tourism.

From 1982–1989, a total of 17 lynx (6 females, 11 males) of Carpathian origin were officially reintroduced in the area of the subsequent Šumava National Park (Bufka & Červený 1996).

It is not known if any of the 5–7 lynx released in the Bavarian Forest from 1970 to 1974 (Festetics 1981, Stehlik 2004) or their descendants survived until the reintroduction in Bohemian Forest. Therefore, we assume that only this second reintroduction in former Czechoslovakia provided the founder group of today's lynx population. Nevertheless, the clandestine release of lynx on the Bavarian side in the 1970s is still responsible for negative attitudes towards lynx and therefore poses till the present day a challenge for the conservation of the species.

Transboundary cooperation in lynx conservation and monitoring started in the early 1990s. Cooperation was neither institutionalised nor methodically harmonised. It comprised exchange of information and experience with data collection and radio-tracking.

The first transboundary assessment on population level was done in 2000 (Wölfl et al. 2001). The data were of very uneven quality, stemming from diverse compilation methods of different intensity (chance observations, snow tracking and questionnaires) and could not be evaluated due to lacking documentation and verifiability. However, this information provided a basis for next steps and all data collected since the 1970s have represented a valuable dataset, which enables current long-term population development studies.

As monitoring data inform conservation actions of almost any kind, the focus lay not only on improving the monitoring, but also to harmonise data collection methods. In Bavaria, the monitoring standards developed by the SCALP Expert Group (Molinari-Jobin et al. 2003) have been applied since 2002. This was possible, because a widespread network of volunteers trained to record and document lynx signs was established at an early stage. This enabled the evaluation of lynx reports according to the SCALP categories (Molinari-Jobin et al. 2021). Since 2007, the quality of the monitoring has further been improved by applying camera-trap surveys (e.g. Wölfl 2008, Wölfl et al. 2009, Weingarth et al. 2012). Nevertheless, it soon became clear that for a sound population assessment, monitoring standards must be applied transboundary and on a larger scale.

Trans-Lynx project

Finally, from 2013–2015 the Trans-Lynx Project, co-financed by the EU, targeted the entire BBA lynx population (some 7,500 km^2) and involved several GO and NGO institutions in a transboundary cooperation. The main goal was to implement international monitoring standards, i.e. to harmonise data collection, evaluation, and analysis. The project partners agreed to apply the SCALP criteria, and hence made a big step forward regarding transboundary monitoring standards at population level. Other goals were to integrate stakeholders in project implementation and to develop and strengthen international cooperation.

3Lynx project

In the subsequent 3Lynx project (2017–2020, EU-co-financed) the number of institutions cooperating on transnational level further increased and the area considered was enlarged. In addition to the range countries, institutions from Italy and Slovenia joined to expand the needed expertise. The 3Lynx project continued where the Trans-Lynx project ended and added a next step: an interna-

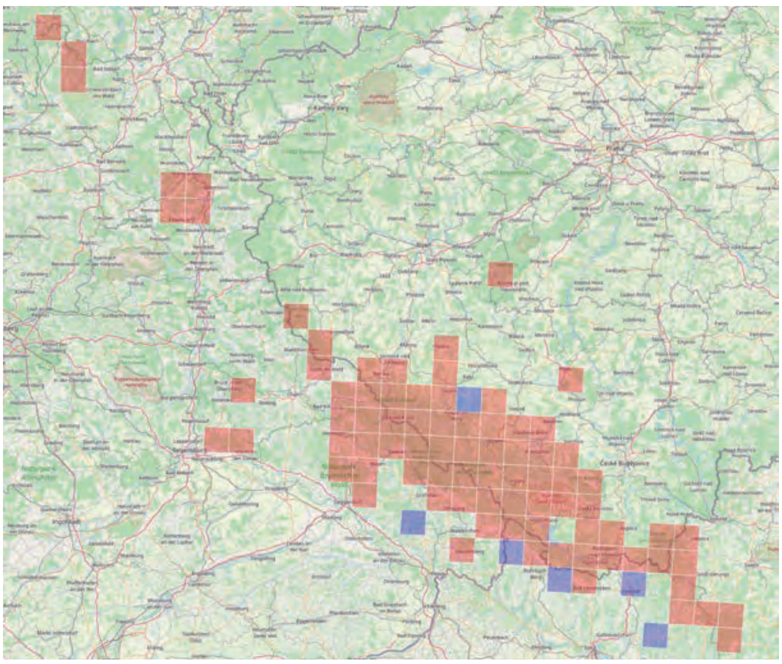

Fig. 1. Distribution of the BBA lynx population in lynx year 2018 (1.5.2018–30.4.2019) based on hard fact data (C1, red) and confirmed data (C2, blue).

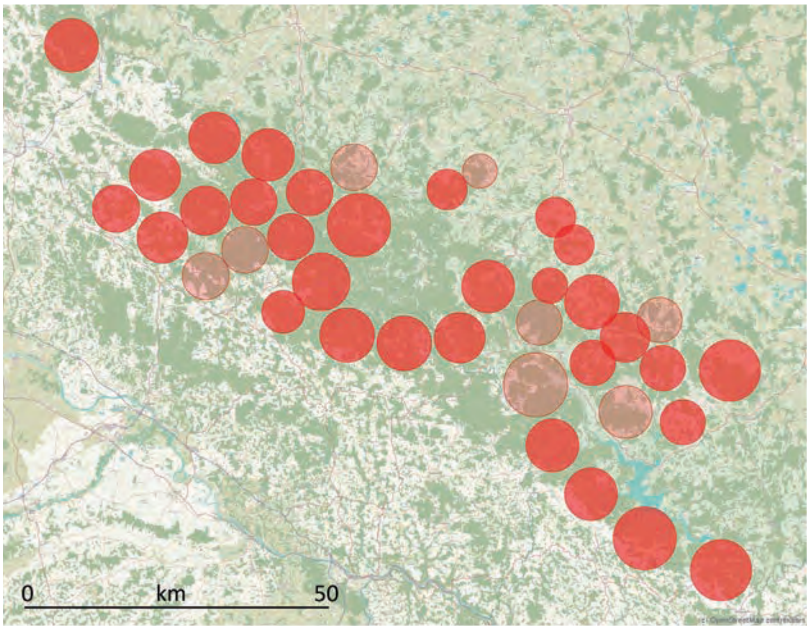

Fig. 2. Map of home ranges of reproducing females with kittens (red) and resident females without confirmed reproduction (light red), recorded in the monitoring year 2018/2019 (1.5.2018–30.4.2019).

tional conservation strategy on population level. The 3Lynx project hence focused on four topics: (1) international cooperation, (2) lynx monitoring, (3) communication and (4) conservation strategy.

As reliable monitoring data are the basis for decisions in lynx conservation and management, a fundamental goal of 3Lynx is (still) the improvement and harmonisation of monitoring from data collection to interpretation. As most important monitoring method, camera-trapping was intensified and extended over an area of 13,000 km^2, encompassing more than the currently known distribution range of the BBA lynx population (Fig. 1). The camera-traps were installed year-round with 2–10 cameras per 100 km^2, depending on confirmed or assumed lynx reproduction zones. As females with kittens are the most important indicator for the vitality of the population, the objective was to record all reproductive units (Fig. 2). For the whole BBA lynx population, we realised a total count of family groups, collected data on distribution, minimum population size, mortality, natality, sex and age structure, dispersal and genetics. Furthermore, by comparing two consecutive monitoring periods we could gather population-wide data about survival of subadult and adult lynx. This information helped us assessing the importance of the major threats to the BBA lynx population: illegal killing, inbreeding, and habitat fragmentation (Mináriková et al. 2020, Wölfl et al. 2020).

The participative monitoring approach pursued in 3Lynx aimed at improving relations with stakeholders, mainly hunters and foresters. Involving all key stakeholders from different countries and languages is a communicative challenge and requires a good coordination of the project activities. We organized mutual stakeholder visits in each of the five participating countries. This gave the stakeholders the opportunity for information exchange and learning about regional approaches to lynx management and conservation. Transnational projects face diverging administrational, legal and socio-political conditions in their countries that often hinder the adaptation of harmonised solutions throughout the entire area, despite the lynx face the same threats in all three countries. This is especially challenging for the development of the lynx strategy on BBA population level (Wölfl et al. 2021).

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Eurasian lynx in the Dinaric Mountains and the south-eastern Alps, and the need for population reinforcement

Eurasian lynx *Lynx lynx* was reintroduced to the Dinaric Mountains in 1973 to bring back an extinct autochthonous keystone species, but also to enrich the hunting grounds. The institutions involved in the reintroduction were aware of the danger of genetic isolation and warned about the importance of connectivity between the lynx populations in the Dinaric Mountains and the Western Alps for their long-term stability. Unfortunately, these populations never connected and the once thriving Dinaric population declined dramatically. Today, lynx in the Dinaric Mountains and the neighbouring south-eastern Alps are again on the brink of extinction. To prevent this, reinforcement of the population is currently taking place within an EU-funded "LIFE Lynx" project. While the main threat is indisputable – the population is highly inbred – the relative importance of the other factors causing the decline is still under debate, especially because the reintroduced lynx in the Dinaric Mountains was legally hunted for more than two decades. Here, we describe the most important historical events which enabled the lynx to recolonise Slovenia, Croatia, Northeastern Italy and Bosnia and Herzegovina (BiH) and highlight the main management decisions that were made during the lynx population expansion. Since the hunters were the promotors of the reintroduction efforts but had also carried out all the hunting activities, we discuss also the relevance of hunting for the lynx population development in the region.

Lynx reintroduction and rapid population expansion

Eurasian lynx was extirpated from the Northern Dinaric Mountains and south-eastern Alps (Fig. 1) at the end of the 19th century and the beginning of 20th century. In 1973, Slovenian hunters and foresters reintroduced six lynx (three females and three males, including a mother and her son, as well as probably a brother and a sister; Štrumbelj 1974) from Slovakia and these animals represented the founders of the new Dinaric – SE Alpine lynx population. The main aim of the reintroduction was to bring back an autochthonous apex predator and thus restore the balance of the ecosystem. It was even emphasised that hunters cannot select for prey in the same way as native predators and that lynx will positively influence the forest growth through its selective predation of wild ungulates (Čop 1972). Čop (1994) clearly stated that an important purpose of the reintroduction, if it succeeded, was also the enrichment of the state-owned hunting ground proposing the reintroduction, with additional trophy species for hunting.

Questionnaires, designed by the Slovenian Institute for Forestry and Wood Production (SIFWP) were sent via hunting associations to gather information about lynx distribution, estimated abundance, reproductive success, and predation. SIFW regularly informed the hunting organisations about the development of the lynx population. Encouraged by Janez Čop, Croatian forester and hunting management expert Alojzije Frković started gathering lynx data in cooperation with hunters in Croatia in 1973 (Frković, 2001). A good collaboration with Croatia enabled a constant flow of information also to the Croatian stakeholders, and vice versa, which helped building a trustful relationship between the experts and the hunters. This is an important distinction from several other reintroductions of Eurasian lynx that were conducted in the same period, sometimes including clandesine releases of lynx and often without appropriate informing of the public and hunters, e.g. in Switzerland and probably Austria (Breitenmoser and Breitenmoser-Würsten 2008). This likely still has some negative consequences for people's attitudes toward the species.

The lynx population in Slovenia was determined to be abundant enough for legal hunting in 1978, i.e. five years after reintroduction. The hunting was controlled and could be undertaken only within the defined "lynx core area", covering roughly 4,000 km^2 and within the prescribed hunting season (October–February). Meanwhile, lynx had a status of a game species in Croatia and the first animal was hunted in 1978. Hunting in Croatia continued without any restrictions until 1982 when the species was protected by a Decision on Special Protection of Lynx. To ensure the cooperation with hunters and to collect data about population status, the State Bureau for Nature Protection (SBNP) in Croatia, issued yearly hunting quotas for a limited hunting season until 2013, when Croatia adopted the Habitats Directive (Sindičić et al. 2010, 2016).

In Slovenia, the Hunting Association proposed unlimited hunting of lynx outside of the core area in 1986. The SIFWP strongly opposed the idea due to predicted negative effect on population expansion towards the Alps and proposed a compromise allowing hunting under restricted hunting period and a ban on hunting females with kittens. Opinion-based estimate of the lynx population size in Slovenia at the time was around 200 animals (Kos et al. 2012).

In 1990, the zonation of hunting was terminated as a management measure, although hunting was still prohibited at the border with Italy and Austria with the aim to allow lynx to immigrate into these countries. Čop (1994) and Čop & Frković (1998) warned that the hunting regime was not strict enough and proposed restrictions. Furthermore, the breakdown of Yugoslavia in 1991 caused an impediment for data collection, including mortality records (Fig. 2), as well as for control of regulated hunting, especially in Croatia and BiH.

In 1994, the Slovenia Forest Service (SFS) took over the management of the lynx in Slovenia and the hunting quotas decreased following the recommendation of Čop (1994), and new legislation was accepted by the government in 1993, which listed lynx as protected species in Slovenia with legal hunting based on a quota. The quota was established based on monitoring results of previous years. Protection was reinforced when the country joined the EU in 2004 and ratified the European legislation (Habitats Directive), which caused a complete halt of legal hunting (Sindičić et al. 2009).

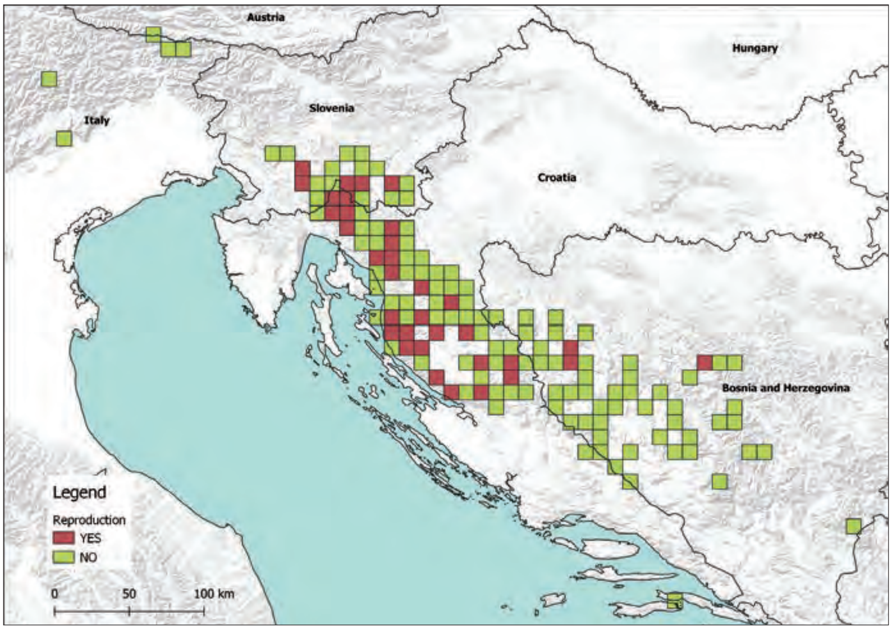

Fig. 1. Lynx distribution range according to C1 and C2 data (SCALP categorization; Molinari-Jobin et al. 2003), including data from systematic camera trapping, in the Dinaric Mountains and SE Alps between years 2018 and 2019 (data extracted from lynx.vef.hr database (21.9.2020) and Trbojevič & Trbojević 2018).

In Bosnia and Herzegovina (BiH), lynx had a different status between the two governing entities (Republic of Srpska and Federation of Bosnia and Herzegovina) but did not gain full protection by law until 2009. Generally, there was also a lack of interest for the species from the governmental institutions and a lack of funding for any research or monitoring activities. The first confirmed record of lynx returning to BiH is from 1980 (tracks) and hunting started in 1984. Hunting was not restricted and the mortality data was the main information collected about the lynx population (Soldo 2001). By using questionnaires, data on mortality records for the past decades were reconstructed (Trbojević & Trbojević 2018), while other methods for monitoring have started to be used only in recent years (Trbojević 2019).

Lynx population decline and enhanced internatioanl collaboration

The reintroduction of lynx into the Dinaric Mountains was internationally recognized as the most successful of all reintroductions in Europe at the time (Breitenmoser-Würsten & Breitenmoser 2001). International collaboration strengthened in the new millennia especially in the Alpine arc, and the monitoring activities in Slovenia became more systematic in the 2000s with the implementation of the SCALP data categorization criteria (SCALP stands for the Status and Conservation of the Alpine Lynx Population; Molinari-Jobin et al. 2003).

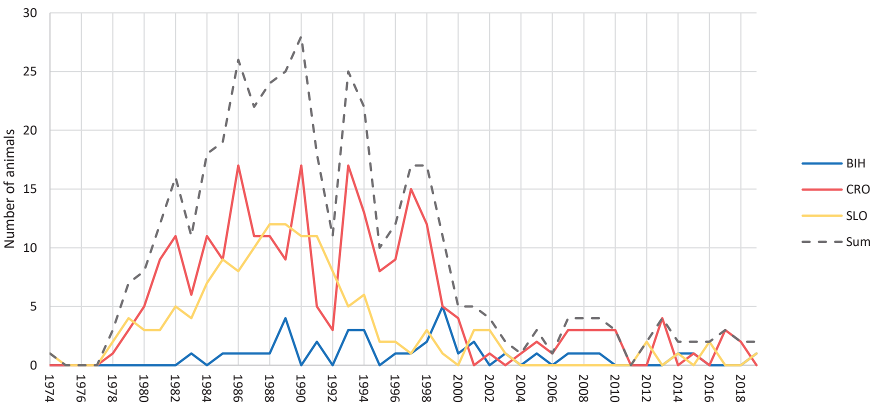

Fig. 2. Recorded lynx mortality in Slovenia, Croatia and BiH between 1974 and 2018 (Soldo 2001, Frković, 2001, Sindičič et al. 2016, Čop 1994, Slovenia Forest Service 2018, Trbojević Trbojević 2018).

Lynx population abundance in Slovenia slightly dropped in the 1990s (Fig. 3) to 40–50 animals (Staniša et al. 2001). In the next pentad (2000–2005) stability was still officially reported despite the suspicions of increased illegal killing and local decline of lynx records. Permits for lynx hunting were issued in areas where opportunistic data and damages to livestock indicated constant lynx presence although they were often not reached in the later years (Fig. 3). According to some experts, the hunting permits reduced probability for poaching (Koren et al. 2006), but unconfirmed rumours about regular poaching of the lynx appeared simultaneously.

Likewise, suspicions of poaching started in Croatia after the species was protected, and Sindičić et al. (2016) reported 60% (18 cases per year) of all recorded mortality cases in Croatia after the protection (between 1999 and 2013) were due to poaching. That was substantially higher than the estimated poaching rate when legal hunting was permitted (10 cases per year; up to 10%; Sindičić et al. 2016). After 2009, when no lynx mortality was recorded in Slovenia and the records in Croatia drastically decreased (Sindičić et al. 2016), it became also generally accepted that the lynx population in the Dinarics is far from stable. The population of lynx in Slovenia in the early 2000s was estimated to be 15–25 and in Croatia 40–60 animals, although it is important to emphasise that the estimation was not based on coordinated monitoring. The range shrank, with the number of records dropping especially in the peripheral areas of the population distribution, in Dalmatia and eastern-central Croatia and in the SE Alps, Slovenia (Kos et al. 2012, Huber et al. 2013).

From 2007 on, research and monitoring have been improving and a common Slovenian-Croatian management strategy was prepared, but was never adopted by the governments (Majić Skrbinšek et al. 2008). Important advance in knowledge was gained from genetic studies, which confirmed high level of inbreeding in the population and demonstrated a dramatic drop in the effective population size, which became too low for the long-term persistence (10.2–17.5 95% CI; Skrbinšek et al. 2019; Polanc 2012, Sindičić et al. 2013a, 2013b). A need for genetic remedy was advocated ever since but funding for it was assured only in 2017 when the EU-funded LIFE Lynx project was launched (www.lifelynx.eu).

The role of hunters and Dinaric lynx today

The importance of hunters for the existence of lynx in the Dinaric Mountains is undisputable. After they reintroduced the lynx in 1973, they were in charge of lynx management, including proposing the hunting quotas and carrying out opportunistic monitoring in collaboration with the SIFWP. If hunting were not planned, it is doubtful whether hunters in that period would have carried out the reintroduction of this large carnivore to the Dinaric Mountains. Hunting of lynx was based on presumed vitality of lynx population and quotas were planned from the late 1970s until 2003 in SLO, until 1998 in CRO, and until 2009 in BIH. Between 1977 and 2008, when lynx in the Dinaric Mountains and SE Alps were legally hunted, 296 animals were legally harvested in the three countries (Zavod za gozdove 2018, Trbojević & Trbojević 2018, Sindičić et al. 2016), which represented 75% of all recorded lynx mortality in the respective countries (Fig. 2). Despite regular hunting, the population grew, spatially spread and colonised the whole northern part of the Dinaric Mountains and a part of the SE Alps.

It remains unknown to what degree hunting (legal and illegal) might have slowed down the expansion process and sped up the decline of the population. Some reintroduced populations in Europe are not spatially expanding due to high rates of illegal killing (Müller et al. 2014, Heurich et al. 2018). It remains unclear whether regular hunting quotas reduced the probability of illegal killing and the total number of removed animals from the population, as assumed for instance by Koren et al. (2006).

With a high support from and tight collaboration with the hunters, accompanied by their publicly advocated conservationist philosophy, we are confident that today the lynx reinforcement process undertaken within the LIFE Lynx project (www.lifelynx.eu), is giving lynx in the Dinaric Mountains and the SE Alps a second chance. The project aims to save the Dinaric–SE Alpine lynx population from extinction by improving the genetic and demographic perspective well into the 21st century. Before 2021, 7 lynx have already been translocated from the Carpathian population to the Dinaric Mountains and further releases are planned for the next years (Krofel et al. 2021). In addition to this, a new population nucleus ("stepping stone") in the Slovenian Alps was created with 5 animals in 2021. The aim is to bring the SE-Alpine nucleus closer to the Western Alpine population with a vision of creating an interconnected metapopulation with regular gene flow, which will help reduce negative impacts of habitat fragmentation and improve the prospect of both populations.

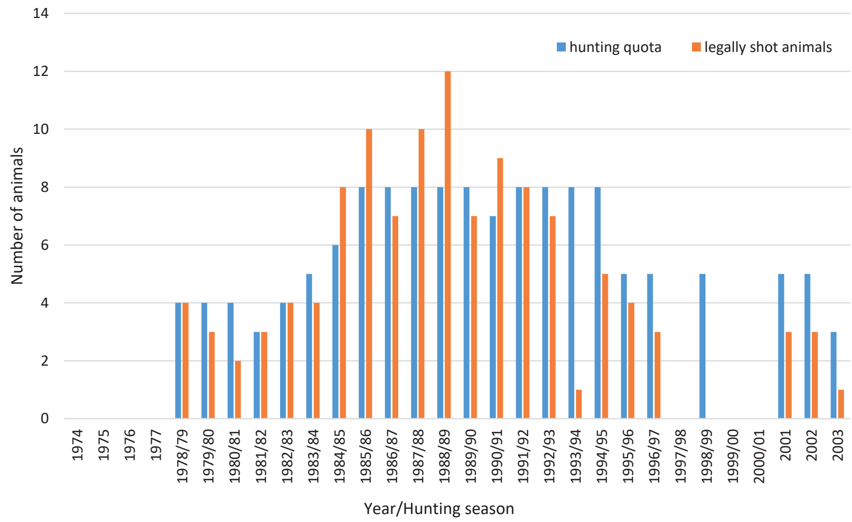

Fig. 3. Lynx hunting quotas and legally shot lynx in Slovenia between 1973 and 2004. For some years, data was available per calendar year, while the majority of the records were available per hunting season (during the winter) (Slovenia Forest Service, 2016).

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The development of the Harz lynx population

Between 2000 and 2006, 24 zoo born lynx *Lynx lynx* have been released into the Harz Mountains HM in central Germany. In the monitoring year 2010/11, 25 cells of the EU reference grid were occupied by lynx belonging to the Harz Lynx Population HLP. In the same season, the first reproduction outside the HM was proven. Until the monitoring year 2018/19, the number of cells of the EU monitoring grid occupied by the HLP has increased to 84. This represents an average annual increase of 7.4 grid cells. Although the mountain range is surrounded by major roads and landscapes with low forest cover, reproducing females have established territories in five different areas outside the HM. Telemetry, genetic and photo data show that single male dispersers can be found in distances of up to 309 km from the source population in the HM, whereas reproducing females have not been proven further than 100 km away from the population centre and a female without cubs has been reported in a maximum distance of 143 km.

In the 1970s, the first suggestions were formulated to reintroduce lynx into the HM in central Germany (see Stahl 1972). After that, the discussion lasted almost three decades before in 1999 the political decision was taken to start such a project. The Ministries for Agriculture and Conservation of Lower Saxony accompanied by the Hunting Association of Lower Saxony became executors of the project. The practical work was carried out by the Harz National Park. In early summer 2000, the first lynx individuals were transferred to the HM, set into an enclosure in the central part of the national park and released after a few weeks of acclimation. All 24 (15 females, 9 males) animals released until 2006 were captive bred individuals from German and Swedish enclosures.

The use of zoo born lynx, the scientific support of the project and the suitability of the HM as a project area have been intensively discussed before and during the first years of the program (Wotschikowsky et al. 2001, Schadt et al. 2002a/b, Barth 2002, Kramer-Schadt et al. 2005, Wotschikowsky 2007). In the following, we will give an overview over the development and range increase of the population almost twenty years after its establishment.

Methods

Study area

The Harz Mountains in central Germany (51°43’27.8’’N 10°43’56.7’’E) is a low mountain range covering an area of 2,200 km² with elevations ranging up to 1,141 m. The mountains touch the three German federal states of Lower Saxony LS, Saxony Anhalt SA and Thuringia TH. 250 km² of the area are under the protection of the Harz National Park.

About 75 % of the mountain range are forested. The forest is largely dominated by European spruce *Picea abies* of anthropogenic origin but also holds natural spruce stands in elevations higher than 800 m. Due to an immense human impact on the vegetation (mining, charcoal burning in historic times) beech forest *Fagus sylvatica*, once dominant in the area, nowadays appears mainly at the edges of the mountain range. The relief is shaped by several largely undisturbed rivers, many of them originating in the moors in the higher elevations of the HM.

At high elevations, the ungulate population is dominated by red deer *Cervus elaphus*. Wild boar *Sus scrofa* frequently occurs in the forests. Roe deer *Capreolus capreolus* is rare at higher elevations with high snow cover during the winter season, but is more dominant at lower altitudes. A few isolated populations of introduced mouflon *Ovis amon* occur mainly in the eastern and north-western parts of the HM. Outside the HM, red deer are absent and roe deer and wild boar are the dominant ungulate species.

The landscape surrounding the HM is dominated by agriculture and the edges of the Harz forest represent a sudden change in habitat quality. In the western and southern foreland of the mountain range, the forest cover reaches a maximum of about 25 % whereas north and east of the area, forest is scarce due to fertile soils allowing profitable agricultural production.

Lynx monitoring

The Harz National Park is responsible for the lynx monitoring in the two federal states of Lower Saxony (LS) and Saxony Anhalt (ST). The neighbouring states (Hesse, North Rhine-Westphalia, Thuringia) have implemented their own monitoring infrastructures. Within the whole population range, lynx monitoring follows the national guidelines (Kaczensky et al. 2009, Reinhardt et al. 2015) which are based on the SCALP criteria and distinguish into C1, C2 and C3 records (Molinari-Jobin et al. 2003). The results have to be reported at an annual meeting of lynx experts responsible for the monitoring in the federal states. The national agency for nature conservation (BfN) collects the data and produces an annual distribution map based on the EU monitoring grid. Each grid cell covers an area of 100 km² (10 x 10 km). A grid cell is regarded as occupied by lynx if there was at least one C1 record or at least two C2 records within that cell. Telemetry data of evidently dispersing lynx do not count towards presence within a grid cell. A lynx is considered resident in an area if it has been confirmed with C1 or C2 records covering a period of at least six month (Reinhardt et al. 2015). In 2009, lynx monitoring was standardized nationwide. Including the monitoring year 2009/10, all grid cells occupied by resident lynx of the HLP were located within the HM. Only in the following years did individuals establish permanently outside the low mountain range. Therefore, in order to describe the range development of the Harz Lynx Population (HLP), all grid cells from the monitoring years 2010/11 and 2018/19 in the federal states of Lower Saxony, Saxony Anhalt, Thuringia, Hesse and North Rhine-Westphalia were considered (BfN 2011, BfN 2019). In 2018/19, two grid cells in western North Rhine-Westphalia occupied by a zoo escapee were discounted.

Chance observations

Chance observations of lynx such as sightings, tracks, prey remains etc. reported by hunters, foresters and the general public represent the basis of the monitoring and have been collected since the first lynx were released in the summer of 2000. Lynx pictures taken as chance observations occasionally offer the opportunity to identify individuals by their coat pattern (Weingarth et al. 2012) and to recognize dispersers.

Camera trap monitoring

In 2001, the opportunistic use of camera traps has been implemented. At that time, the devices have mainly been placed at prey remains in order to gain C1 lynx evidence. Between 2014 and 2017, a systematic camera trap monitoring has been conducted with 60 sites and two opposing cameras at each site. Data on lynx abundance and density have been collected this way in three different study areas in the HM (Anders & Middelhoff

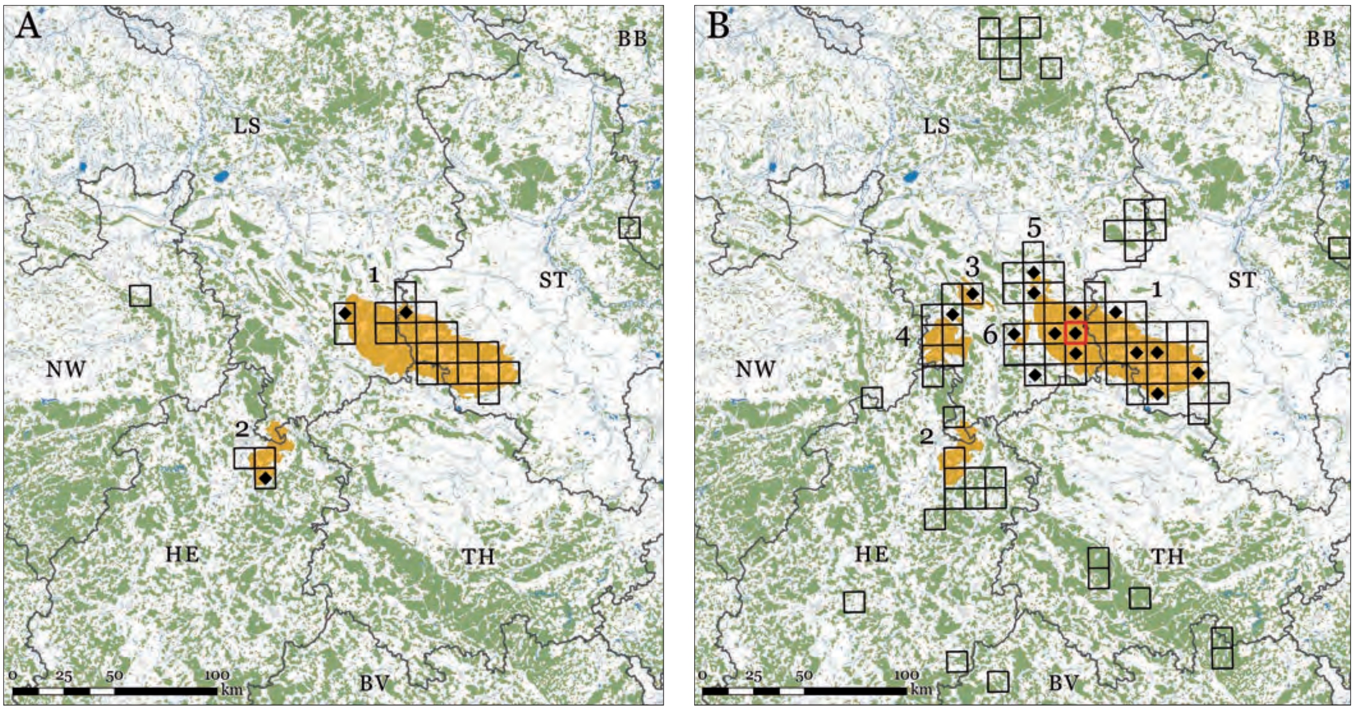

Fig. 1. Distribution area of the Harz Lynx Population in the monitoring years 2010/11 (BfN 2011) (A) and 2018/19 (BfN 2019) (B). Each cell of the EU reference grid covers 100 km². Grid cells with black dots hold reproduction evidence. Between 2016 and 2019, there has been no evidence of reproduction in HE. B: The orange marked areas with numbers define the six reproduction areas: 1 Harz, 2 Kaufunger Forest, 3 Hils and surrounding forests, 4 Solling, 5 Hainberg, 6 Westerhoefer Forest. The red grid cell marks the population centre.

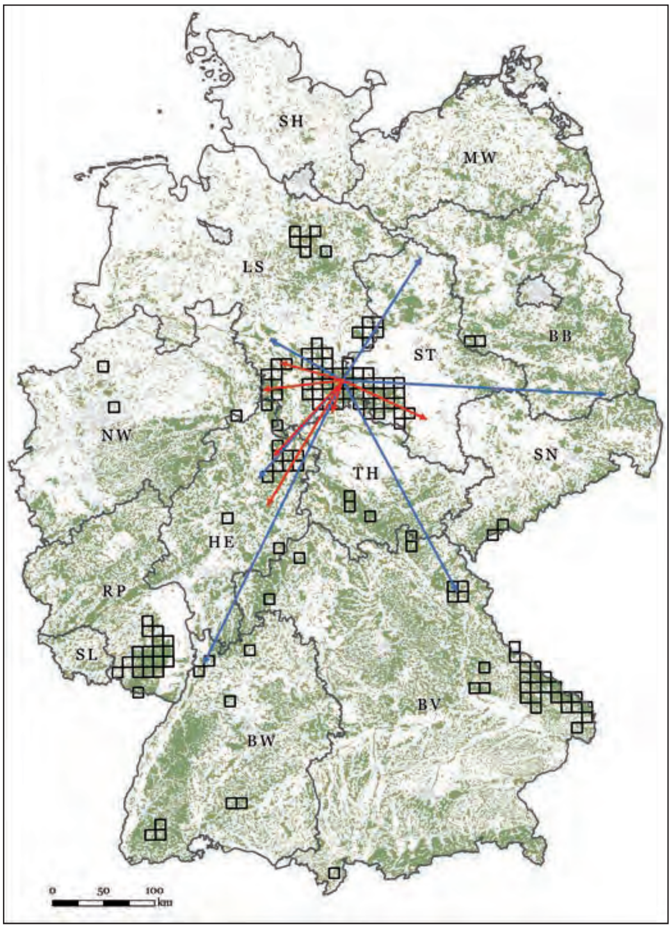

Fig. 2. Maximum distances of male and female lynx from the population centre in the Harz Mountains. Green: Forest cover in Germany. Grey lines are borders of the federal states: Schleswig-Holstein (SH), Mecklenburg-Western Pomerania (MW), Lower Saxony (LS), Saxony Anhalt (ST), Brandenburg (BB), North Rhine-Westphalia (NW), Hesse (HE), Thuringia (TH), Saxony (SN), Rhineland Palatinate (RP), Saarland (SL), Baden-Wuerttemberg (BW), Bavaria (BV). Grey grid cells show lynx distribution in the monitoring year 2018/19 (BfN 2019). Beside the Harz Population, lynx have been reintroduced into RP since 2016. BV holds parts of the Bavarian-Bohemian-Austrian Lynx Population. Red lines show maximum distances of female detections from the population centre in the Harz Mountains. Blue lines show the maximum distances of male detections from the population centre. Six male detections and six female detections with the highest distances have been chosen for graphic representation.

2016, Middelhoff & Anders 2018). Each of the overlapping study sites covers an area of at least 741 km². The data has been analysed with the module CAPTURE in the Computer program MARK (White & Burnham 1999). Moreover, since 2015, camera trap projects with the use of 10 to 22 devices have been alternating between all areas with verified lynx reproduction outside the HM in order to identify, both, resident lynx and juveniles before their dispersal. Like lynx photographs from chance observations, camera trap pictures can be used to identify dispersers between different study areas (see Singh et al. 2013).

Telemetry

Between 2008 and 2019, 23 lynx (15 m, 8 f) were fitted with GPS/GSM collars. The animals had been previously trapped in box traps and immobilized from a blowpipe or in two cases, immobilized with a tranquilizer gun, without prior trapping. The collars were either produced by VECTRONIC AEROSPACE, Germany or LOTEK, Canada. Another two individuals (1 m, 1 f) have been equipped with VHF collars by WAGENER, Germany. Telemetry data have originally been collected in order to gain information on home range sizes and nutrition, and more recently, on dispersal routes from the HM (see Anders et al. 2012). Here, these data are used to show dispersal directions and distances from the source population.

Genetic monitoring

A genetic monitoring has first been implemented in the HLP in 2009 when the Senckenberg laboratory for conservation genetics was designated as the German reference laboratory for wolf and lynx genetics. Until autumn 2019, a total of 179 lynx individuals from the HLP have been identified from blood, saliva, hair and scat samples, among them 10 founder individuals. Individuals from the HLP can be distinguished from those of other populations and due to founder effects even from zoo lynx (Mueller et al. 2020). Accordingly, genetic analyses are used here to verify the Harz origin of lynx, to define start and end points of lynx dispersals and moreover, to gain C1 lynx evidence.

Distances of lynx individuals from the population centre

As the maternal home ranges are known only for a small number of dispersers from the HLP, we used the erstwhile location of the release enclosure in the Harz National Park as an equal starting point to measure dispersal distances. We measured the maximum distances dispersers from the HM, dispersers with unclear starting points and resident lynx outside the HM have gained from this population centre (PC). Moreover, we took single C1 chance observations into consideration when females where photographed with cubs or clearly visible genitalia. We measured the distances between the locations of observation and the PC.

Results

Range increase

Until the monitoring year 2009/10, all grid cells occupied by lynx within the range of the HLP, were located inside the HM. In the following season 2010/11, five out of a total of 25 occupied grid cells were located outside the HM (Fig. 1). In the season of 2018/19, 84 occupied grid cells appeared on the distribution map (Fig 1). 48 (57 %) of them do not touch the HM. Most of the latter are located west and south of the HM. 19 grid cells appear north and east of the HM (see BfN 2011 and 2019). Between 2010/11 and 2018/19, the number of grid cells occupied by lynx increased by 59 cells (236%) representing an average increase of 7.4 cells per year.

Lynx abundance and density in the HM

The results of the systematic camera trap monitoring in different study areas inside the HM analysed with non-spatial capture-recapture models ranged between 2,1 and 2,9 independent lynx/100 km². From this, a mean density of 2.5 independent individuals can be derived and an abundance of 55 independent individuals (Anders & Middelhoff 2016, Middelhoff & Anders 2018) which form the source population from which dispersers emerge to settle the foreland of the HM or to migrate over long distances.

Reproduction areas

Inside the HM, the first evidence of lynx reproduction has been detected in 2002. In each of the following years, lynx offspring were recorded. In the monitoring year 2010/11, camera trap pictures showed lynx cubs in northern Hesse (Kaufunger Forest) around 100 km from the population centre in the HM (Denk 2011 and 2012; see Fig. 1). Since then, reproduction has taken place in four more areas outside the HM in distances of 30 to 70 km from the population centre (Hils and surrounding forests: 2013ff, Solling: 2016 ff, Hainberg, 2018ff and Westerhoefer Forest 2018 ff). However, after 2015, the reproduction area in the Kaufunger Forest collapsed. At least two females died of sarcoptic mange (Port et al. 2020, Wölfl et al. 2021).

Distances from the population centre

Between 2010 and 2019 a total of 11 (9 m, 2 f) lynx, that started their dispersal inside the HM and later left the area, have been detected either by telemetry data, adjacent photo trap pictures or genetic evidence. Ten additional males started their dispersal at an unknown location but have been GPS-collared or repeatedly photographed outside the HM. Moreover, three resident females have been repeatedly sampled and photographed outside the HM. The areas where they were once born are unknown, though. All of these animals (n = 24) are either genetically proven members of the HLP themselves or offspring of genetically proven females. In order to find out the maximum distance to the PC reached by female lynx, we considered single C1 photo evidences from Northern Hesse. The pictured lynx females were neither genetically sampled nor photographically identified.

The first of the two GPS collared females that left the HM (Fig. 2) had already given birth to a litter of three when it started to disperse in September 2012 accompanied by at least one of the juveniles. The animal left the HM in an eastern direction (max. distance to PC: 92 km) but returned to the area before the collar stopped to work. In 2014, the second collared subadult female left the HM. It had been caught as an orphan and raised in an enclosure of the Harz National Park. The female established a territory south of the edges of the HM in semi open habitat (max. distance from PC: 34 km) and gave birth to a litter in May 2015 (Anders et al. 2016 a). The female was found dead in December of the same year. The three resident females have been reproducing in different circumjacent reproduction areas (max. distances from PC: 63, 78 and 87 km; see Fig. 2). Unknown females with cubs have been photographed in a maximum distance of 100 km from the PC (Kaufunger Forest, Denk 2013). A single C1 evidence of a female without cubs occurred south of the Kaufunger Forest and 143 km from the PC (Denk 2016).

In contrast to that, single male dispersers from the HM have been verified by telemetry, genetic or photo data in distances up to 258 km from the centre of the population. A GPS collared individual trapped around 90 km northwest of the HM, has later reached the maximum distance of 309 km from the PC (Fig. 2).

Discussion

After the monitoring year 2010/11 and thus more than ten years after the first reintroduction, the density of lynx and the population pressure in the HM have reached a level that made dispersals into the foreland more and more likely. It is at least conceivable that the lynx density within the HM today is in the range of the carrying capacity. The density of independent lynx in the HM, estimated on the basis of non-spatial capture-recapture models, can only be compared to a limited extent with the results described in the literature and determined with different methods. However, these vary from 0.3 lynx per 100 km² in Norway (Sunde et al. 2000) to 4.2 independent lynx in Turkey (Avgan et al. 2014). Similar methodology as in the Harz Mountains is used to determine lynx densities in Switzerland. According to Zimmermann et al. 2020, results obtained with non-spatial capture-recapture models ranged from 1.44 individuals/100 km² in western central Switzerland to 3.48 individuals/100 km² in the southern Jura. For north-eastern Switzerland and the northern Jura, values of 2.53 and 2.55 individuals/100 km², respectively, were similar to those reported for the Harz Mountains.

The Eurasian Lynx is a species described as highly bound to forest habitat (Haller & Breitenmoser 1986, Breitenmoser & Breitenmoser-Würsten 2008, Rozylowicz et al. 2010). Therefore as expected, the range increase of the population leads west- and southwestwards into areas with a reasonably high forest cover. Whereas the range increase to the east and the north is comparatively low due to a low percentage of forest in these areas. Schmidt (1998) found that during their dispersal, radio collared subadults in eastern Poland apparently followed the distribution of forest habitat.

Nevertheless, animals that leave the HM in either direction have to cross major roads and more or less open agricultural landscape before they reach the shelter of the next forest patches. Anders et al. (2016 b) assumed that beside the forest cover, the permeability of roads around the HM influences the direction in which individuals travel. Roads as migration barriers hamper the speed in which the population spreads. Huck et al. (2010) regard major roads (international roads, express roads, highways etc.) as factors hindering large carnivore dispersal.

In recent years, it has been more likely to identify male than female dispersers in the Harz foreland, whereas Zimmermann et al. (2005) found no sex bias in the proportion of dispersers in the Swiss populations in the Jura Mts and the Alps. Schmidt (1998) reports that the distances travelled during dispersal are farther for males than females. Dispersing males from the HM carry the potential to travel over long distances and therefore might easier accept less suitable habitat. They have in some cases even come close to the ranges of the Palatinate and the Bavarian/Bohemian/Austrian lynx populations and in one case a reproduction between a Harz male and a translocated Bavarian female has occurred (Wölfl et al. 2021). However, the rather moderate dispersal distances of females seem to dictate the velocity of the HLP range increase.

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Situation of the lynx in the Jura Mountains

The present report describes the situation of the Eurasian lynx *Lynx lynx* in the Jura Mountains Mts, shared by France and Switzerland. The species disappeared between the 17th and 20th century and recolonised its natural range from the 1970s following reintroduction in Switzerland. The current distribution in the region covers a total of 13,700 km², including 4,200 km² with "hard fact" evidence of reproduction (data of the biological year 2018/19). In France, the area of regular lynx presence is increasing and consolidates particularly in Franche-Comté region, while almost all suitable habitat is colonised in the Swiss Jura. Between 2004 and 2020, we documented sixteen dispersal movements to adjoining mountain ranges including the Alps (9), the Black Forest and the Schwäbische Alb (6), the Vosges Mts (1) and two to the Swiss Plateau. The Jura Mts could probably form a larger functioning meta-population with the adjoining Vosges-Palatinate Forest, the Black Forest and Schwäbische Alb, and the Alps, although difficult to achieve without reinforcement. The lynx population of the Jura Mts is likely threatened to various extents by traffic accidents, conflicts with human activities and persecution. Furthermore, coordinated health surveillance and genetic variability monitoring are needed to secure population viability.

The Eurasian lynx disappeared in France and Switzerland between the 17th and 20th centuries as a consequence of habitat degradation, direct persecution and the excessive reduction of wild ungulates. In the Jura Mts (Fig. 1), the last evidence reported on either side of the national border included a lynx killed in 1830 near Lignerolle (VD, Switzerland) and another lynx killed near Pontarlier (39, France) (in Breitenmoser et al. 2007). A capture in 1885 at the rim of the French Jura Mts is doubtful (historical review by Eiberle (1972), Herrenschmidt & Leger (1987) and (Schauenberg 1969) in Breitenmoser et al. (2007)). The species was reintroduced in Switzerland in the 1970s, where at least 8 to 10 individuals were released in 3 different sites (Breitenmoser et al. 1998, Breitenmoser & Baettig 1992). Shortly after their initial reintroduction in Switzerland, lynx naturally increased their range and started recolonising France by repopulating forests on the French side of the Jura Mts (Vandel & Stahl 2005). Reintroductions also occurred in the French Vosges Mts between 1983 and 1993 with the perspective of establishing a population there (Vandel et al. 2006). Some accidental or clandestine releases have also been made in the near German Palatinate Forest (Vandel & Wecker 1995). In France, the first observation dates back to October 1974 in the north-east of the department of Ain.

The aims of this report are to review 1) the census and survey technics implemented in France and Switzerland; and 2) the conservation status of the lynx in the Jura Mts with special focus on the conservation challenges and the conservation approaches.

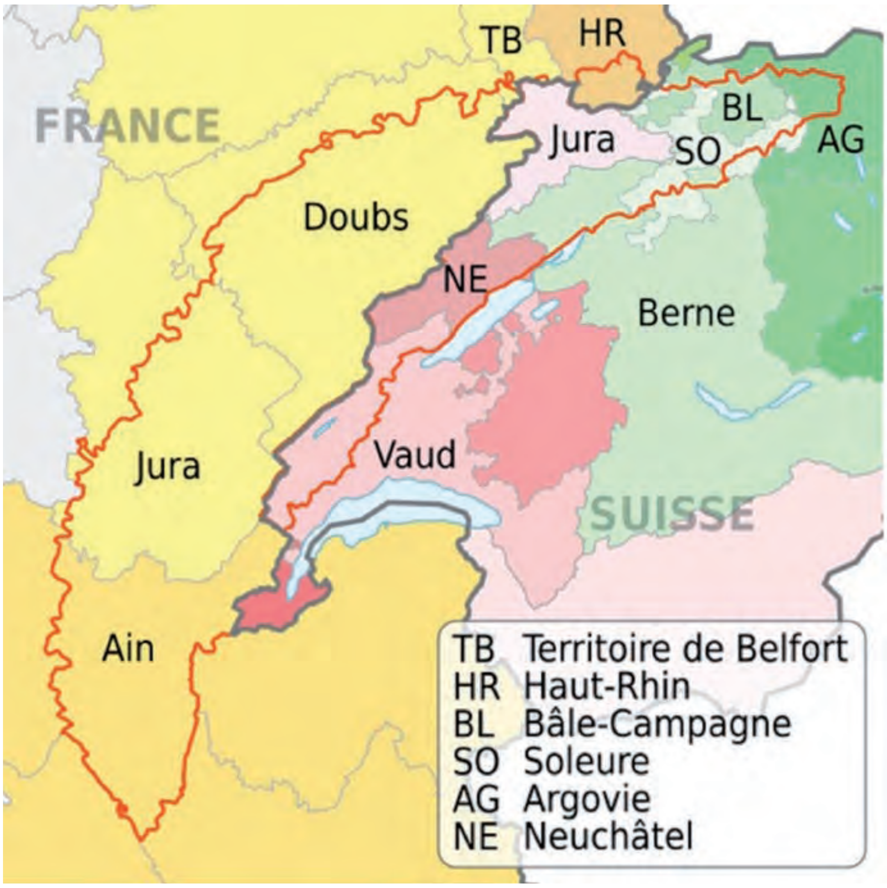

Fig. 1. Map of the Jura Mts with departments on the French side and cantons on the Swiss side (Sémhur 2019 / Wikimedia Commons).

Distribution, population size and trends

Census techniques and density

A stratified lynx monitoring is in place in both countries.

France: Monitoring started in 1998 based on a participative network involving 3,500 trained field experts who collect presence signs all year long. For each presence sign detected, a standardized form is filled out with all the technical criteria needed for further analysis. Data are further examined and validated by a professional agent from the OFB; only recorded signs of lynx that met the standardised criteria are retained (available at http://carmen.carmencarto.fr/38/Lynx.map#).

Since 2011, intense camera trapping sessions have also taken place in a large part of the Jura Mts in order to estimate local population densities. Based on spatial capture-recapture (SCR), data analyses revealed variations in lynx densities (SE) across French Jura counties ranging from 0.24 (0.02) to 0.91 (0.03) lynx per 100 km² (Gimenez et al. 2019).

Switzerland: Monitoring is conducted throughout the country since 1995. Observations (e.g. dead lynx, photos taken by chance, e.g. with

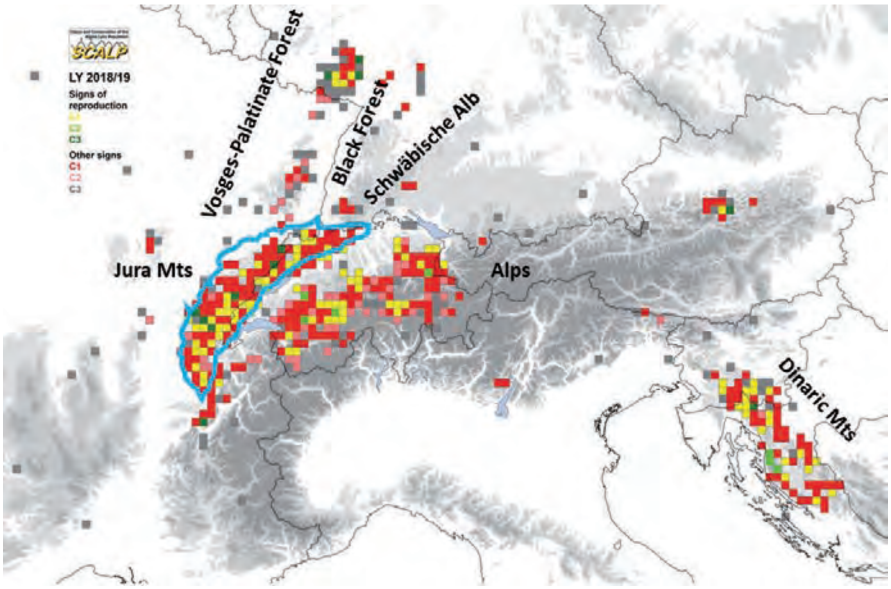

Fig. 2. Observed lynx distribution in the Jura Mts (blue outline), and the adjoining mountain ranges Vosges-Palatinate Forest, Black Forest, Schwäbische Alb, Alps and Dinaric Mts based on a 10 x 10 km grid (SCALP 2018/2019).

a pocket camera) and during the opportunistic camera-trapping, killed wild preys and livestock, tracks and sightings) are gathered year-round at the national and (sub)compartment level by the state game-wardens, hunters, naturalists and the general public and classified in three categories following the SCALP criteria (see Molinari-Jobin et al. 2003 and Molinari-Jobin et al. 2021 for details), and are published online (https://www.koracenter.ch/).

At a smaller scale, at the level of the lynx sub-compartments, the number and density of lynx are estimated by means of photographic capture-recapture models every two to four years. In the Jura Mts sessions were conducted every three years since winter 2006/07 in the reference area northern Jura Mts (882 km^2; Kunz et al. 2019) and since winter 2008/09 in the reference area southern Jura Mts (949 km^2; Zimmermann et al. 2018). Densities (SE) varied between 1.59 (0.6) and 2.55 (0.33) lynx/100 km^2 suitable habitat in the reference area northern Jura and between 1.2 (0.25) and 3.61 (0.85) in the reference area southern Jura. Additional information regarding data types, collection and organisation of the lynx monitoring in Switzerland can be found in Zimmermann (2019). We note that the density estimates are not comparable between France and Switzerland as the approach to estimate the densities differ (spatial vs. non-spatial model, state space or half mean maximum distance moved vs. fixed reference area) (see Gimenez et al. 2019 and Zimmermann et al. 2018 for details on the methodological differences).

Distribution

A lynx distribution map for the whole of the Jura Mts for the biological year 2018/19 was produced following the SCALP framework (Fig. 2). Based on 10x10-km grid cells, the total distribution in the Jura Mts was 13,700 km^2, comprising 4,200 km^2 with "hard fact" evidence of reproduction. The population size is estimated to be around 150 independent individuals (but needs to be taken with precaution regarding the variation in density across areas).

Trends by countries

France: The area of regular lynx presence – based on a biennial period and 10x10 grid cells – has been increasing, from 6,800 km^2 in 2017 to 7,300 km^2 in 2018 (OFB 2021 for updates), and consolidates particularly in Franche-Comté, with a notable increase in the Doubs.

Switzerland: Almost all suitable lynx habitat (2,700 km^2) in the Jura Mts is colonised by the species. The population size has increased from about 30 to 75 independent lynx between 2010 and 2018 (KORA, unpubl. data).

Mortality trends

Mortality data has been recorded in Switzerland since the beginning of the lynx reintroduction. There is an increasing trend since the first records in the 1980s (Fig. 3), which is not surprising as both the range and the lynx numbers increased over the years.

Transboundary movements and connectivity

Between 2004 and 2020, we were able to document eighteen dispersal movements by means of camera trapping and telemetry including some long-distance dispersal to adjoining mountain ranges and the Swiss Plateau (Table 1, Fig. 4). Nine lynx (R67, B232, F39_049, TALO, F01_049, B656, F01_053, F01_059, 2117) dispersed to the Alps, six (B328, FRIEDL, B430, B618, LIAS, TONI) to the Black Forest and the Schwäbische Alb (M. Herdtfelder, pers. comm.), one lynx (BINGO) dispersed to the Vosges Mts (Hurstel & Laurent 2016) and two (B288, B296) to the Swiss Plateau. Two of them turned back (B430, F01_053) and settled in the region where

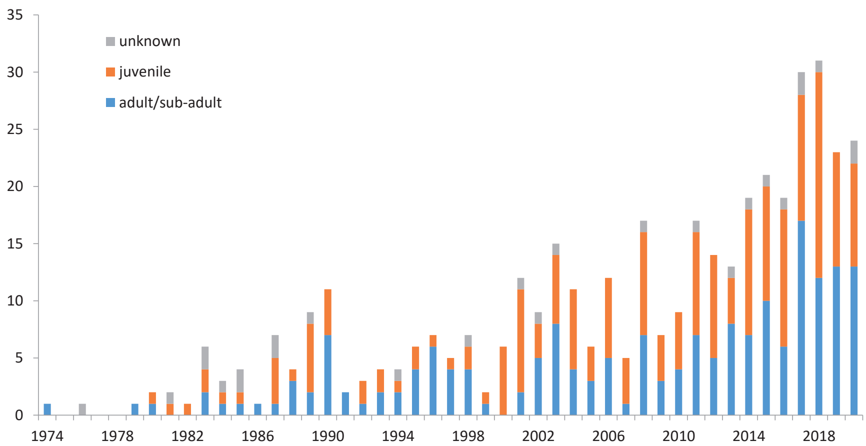

Fig. 3. Evolution of the number of lynx found dead, young orphanes removed from the population and lynx captured in the frame of translocation programs each year (classified according to the age categories: juveniles, sub-adults/adults, unknown) in the Jura Mts. (N= 413).

Table 1. Lynx that dispersed in the last decades from the Jura to adjacent mountains ranges and the Swiss Plateau documented by means of camera trapping and telemetry. Name, sex, last observation in the Jura Mts (month/year), destination, first detection at destination (month/year), distance travelled (sum of distances between consecutive locations from the first location to the last location), reproduced (yes/no/?).

Name	Sex	Last observation in the Jura Mts	Destination	First detection at destination	Distance travelled (km)	Reproduced
R67 [a]	?	02/2004	Swiss Central Alps	03/2006	75	?
B296 [a]	m	01/2011	Swiss Plateau	08/2012	60	yes
B288 [a]	f	01/2011	Swiss Plateau	08/2012	25	yes
B232 [a]	m	02/2011	North-eastern Swiss Alps	02/2012	240	?
B328 [a]	m	10/2012	Black Forest	03/2013	70	no
F39_049 [a]	?	12/2012	Chartreuse (Alps)	10/2013	154	?
TALO [b]	m	05/2013	Haute Savoie (Alps)	05/2014	70	?
FRIEDL [a]	m	05/2014	Black Forest	04/2015	130	no
BINGO [a]	m	06/2014	Vosges	03/2015	178	?
B430 [a,c]	m	09/2014	Black Forest	02/2015	200	no
F01_049 [a]	?	03/2015	Savoie (Alps)	03/2016	57	?
B618 [a]	m	06/2015	Schwäbische Alb	06/2015	185	no
B656 [a]	?	12/2016	Chartreuse (Alps)	06/2017	85	?
LIAS [a]	m	02/2017	Schwäbische Alb	02/2017	290	no
F01_053 [a, c]	m	06/2017	Chartreuse (Alps)	12/2017	130	?
TONI [a]	m	05/2019	Black Forest	12/2019	97	no
F01_059 [a]	f	01/2020	Savoie (Alps)	02/2020	9	?
2117 [a]	?	02/2020	Haute Savoie (Alps)	05/2020	27	?

[a]Camera-trapping, [b]telemetry, [c]turned back and settled in the region where they were first observed

they were first observed. Eleven individuals were males, two were females and five were of unknown gender. So far only the two lynx (B288 and B296) that dispersed to the Swiss Plateau reproduced with certainty. These dispersals to adjacent mountain ranges show that the Jura Mts could probably form a larger meta-population with the adjoining populations of the Vosges-Palatinate Forest, Black Forest, Schwäbische Alb and Alps, once all these mountain ranges are settled by lynx. However, we believe that the establishment of a functioning population especially in the Black Forest, Schwäbische Alb and in the French Alps (except for the Chartreuse) will be difficult to be achieved without further reinforcement, especially with female lynx.

Livestock depredation

Domestic prey in the Jura Mts is primary sheep *Ovis aries* (Vandel & Stahl 1998a, Angst et al. 2000, Stahl et al. 2001a). Flocks are mainly available in the lower parts of the Jura Mts along the northern rim, where they are kept in fenced parks. On the Swiss side the number of sheep is low and flocks are unevenly distributed. Most sheep are kept in small pastures nearby houses. Sheep farming is especially important in the northern Jura in the Clos du Doubs in the canton of Jura, where the only significant losses occurred so far (Fig. 5).

Depredation caused significant public conflicts especially in the French Jura Mts, although the number of sheep killed by lynx is low compared with wolf depredation. In France damages to livestock peaked at the end of the 1980s and 1990s–2000s (max = 410 victims in 1989; Fig. 6). Since the 2000s, damages have dropped to a lower level and varied between 40 and 182 livestock compensated as killed by lynx per year. On the Swiss side, damages to livestock varied between 0 and 48 per year (Fig. 6) and occur mainly in the northern Swiss Jura Mts (Fig. 5).

Threats and priorities

There are several main threats for the Jura lynx population. Traffic accidents represent a major source of mortality (Fig. 7), although this assumption is to be weighted with the fact that road kills have a high chance to be found and reported compared to other causes of death (e.g. illegal killing, diseases). In response to this threat, a predictive tool to estimate the impact of different road management actions on the lynx population viability is under development with a Land Transport Infrastructures, Ecosystems and Landscape project implemented by CEFE/CNRS, CEREMA, CROC and OFB (The ERC-Lynx project: https://sites.google.com/view/erclynx). In addition, conflicts with hunters and with livestock breeders to a lesser extent still represent an important challenge for lynx conservation in the Jura Mts as reported elsewhere (Breitenmoser et al. 2000). Illegal killing is likely to be underestimated and reaffirms the needs to be prevented and persecuted by developing a coherent strategy and guidelines to deal with wildlife crime, e.g. raising awareness among all stakeholders, establish a network of wildlife forensic experts, strengthening scene investigation, and prosecution of illegal activities through

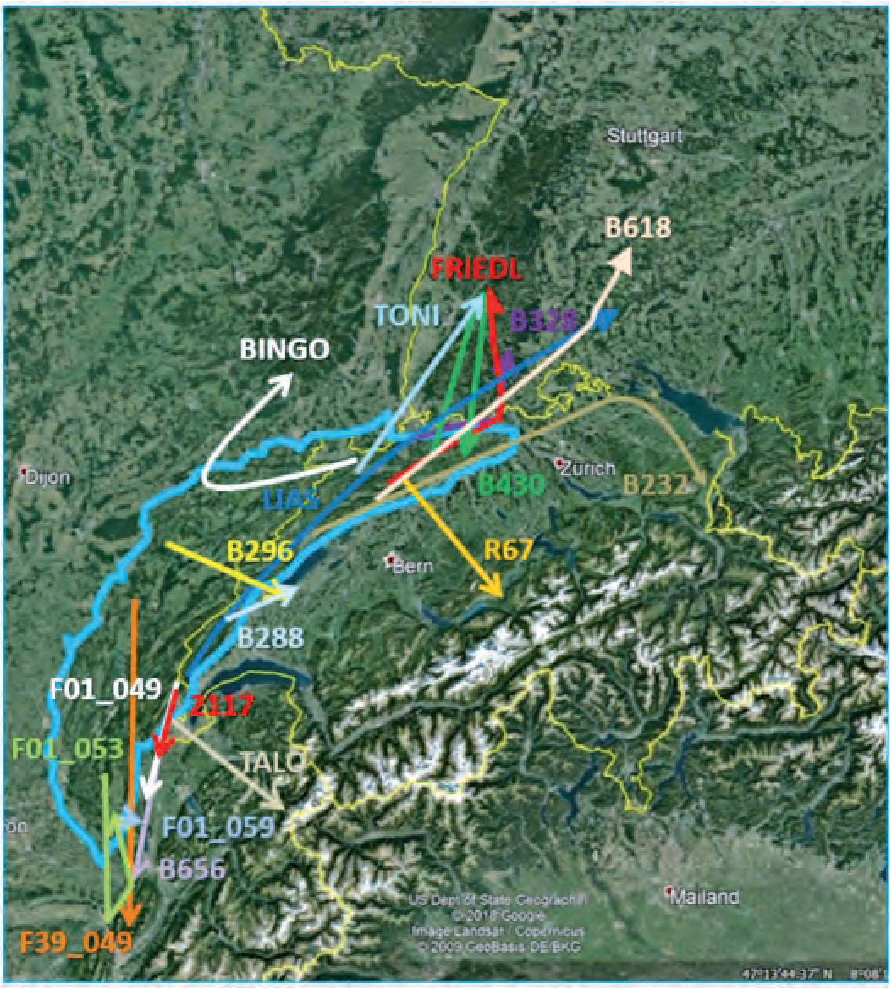

Fig. 4. Lynx that dispersed from the Jura Mts to adjoining mountain ranges and the Swiss Plateau documented by means of camera trapping and telemetry (details in Table 1).

law enforcement. Although no major epizootic outbreak has been experienced until now, cases of diseases such as feline immunodeficiency virus (FIV) and feline leukaemia virus (FeLV) detected in the northern Swiss Jura Mts (Ryser-Degiorgis et al. 2021) could threaten the Jura population, which stresses the importance of a coordinated health monitoring between France and Switzerland.

Finally, population viability requires securing a demographically and genetically healthy population. Heterozygosity, allele frequencies and gene flow between the population in the Jura Mts and adjoining ranges is not well understood and calls for further investigations.

Conclusions

We see several challenges and opportunities for the long-term conservation of this lynx population. In recent years, the Jura population was a source population and served for reintroduction or restocking programs. Between 2003 and 2020, 20 lynx (12 females and 8 males) were captured in the Swiss Jura Mts and released in different mountain ranges in the frame of reintroduction and restocking programs (see Molinari et al. 2021 for details): northeastern Switzerland (Alps), Kalkalpen (Alps), Tarvisiano (Alps), and Palatinate Forest. While such translocations are a good opportunity as they enable to found new populations or reinforce existing ones, they are also a challenge for the Jura population. Given that only healthy young individuals, which should not be too closely related if translocated to the same area, qualify for translocation programs, this could have an impact on the genetic status of the Jura population, especially if the population size is decreasing and there are growing demands for individuals for reintroduction/restocking programs in the coming years. This calls for a genetic transboundary monitoring of the Jura population. The species has colonised almost all suitable habitat, hence there is only a tiny scope for a further increase of the population. The Jura population, which is currently listed as Endangered (EN under Criterion D) will always remain below 250 mature individuals. This is far from the size of a long-term secure population considering genetic aspects and stochastic events. The long-term genetic viability could be achieved if the Jura population was part of a larger meta-population allowing the exchange of individuals between populations, which seems visionary but not illusionary, given the recent records of long-distance movements between adjacent mountain ranges. However, lynx first need to colonise neighbouring mountain ranges with improved connectivity or translocations. The conservation of the lynx in the Jura Mts requests coordinated monitoring, management and applied research. In Switzerland, the lynx management is achieved through the Swiss Lynx Concept (FOEN 2016) which is based on four main pillars: 1) lynx conservation as a main goal, 2) damage prevention, 3) damage compensation and 4) intervention regulation. In France, a National Action Plan is in the process of elaboration, which focuses on increasing monitoring efforts, reducing human-related mortality, reducing conflicts with humans and improving communication and awareness. In the future special emphasis should be given to transboundary convergent methods and cooperation.

At the population level the Office Français de la Biodiversité and the Foundation KORA recently stepped up their collaboration whereas at the meta-population level a cross-border cooperation has been initiated at the Franco-German-Swiss Conference of the Upper Rhine (Upper Rhine Conference; Krebühl et al. 2021).

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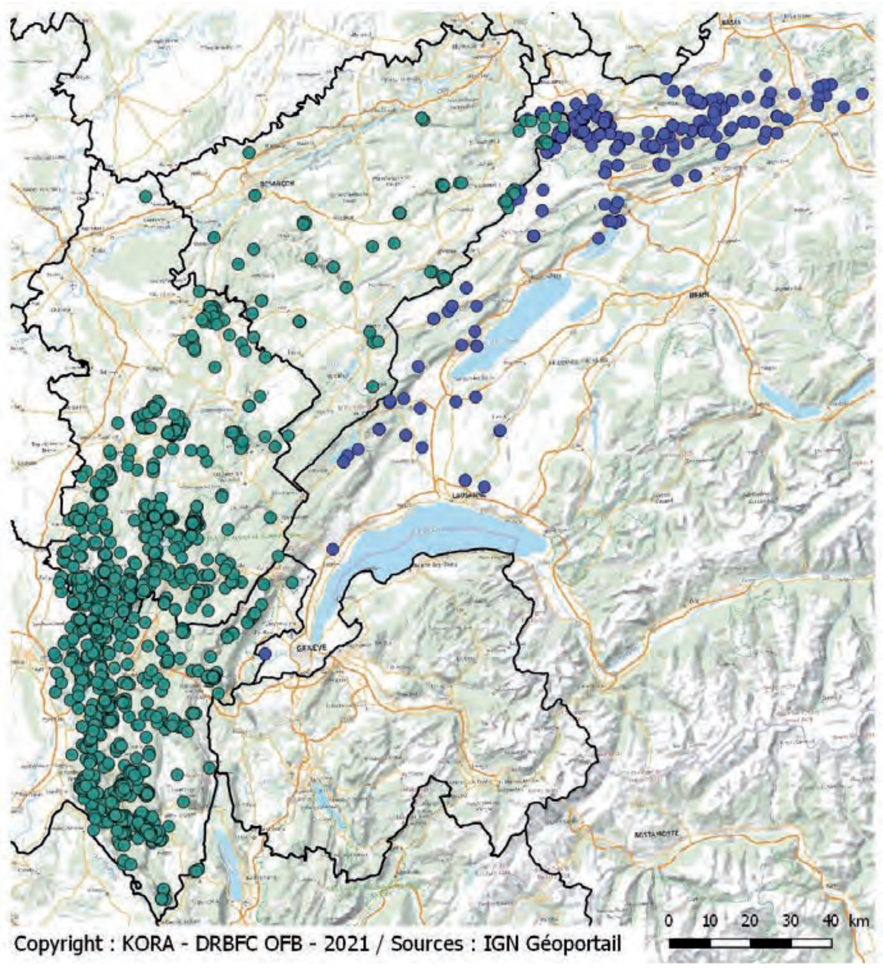

Fig. 5. Distribution of livestock compensated as killed by lynx in the French Jura Mts (N = 4,343, 1984–2019, green dots) and in the Swiss Jura Mts, cantons of Bern, Baselland, Geneva, Jura, Neuchâtel, and Vaud (N = 496, 1973–2019, blue dots).

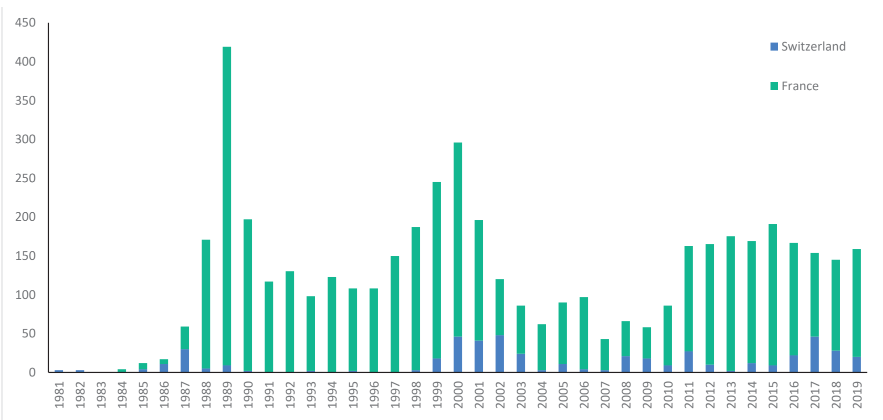

Fig. 6. Evolution of the number of livestock compensated as killed by lynx in the French Jura Mts (in green) since the 1980s (N = 4,343) and in the Swiss Jura Mts (in blue) since the reintroduction in the 1970s (N = 496).

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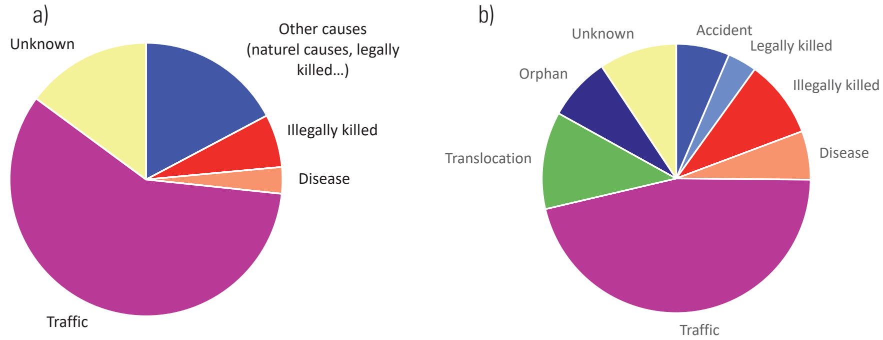

Fig. 7. Causes of death in: a) French Jura Mts (N=255, 1974–2020); b) Swiss Jura Mts (N=171, 1976–2020). In the Swiss Jura Mts, orphaned lynx removed from the wild and lynx captured in the frame of translocation projects were included in the causes of death.

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Situation of the Eurasian lynx in the Vosges Mountains

The Eurasian lynx *Lynx lynx* became extinct in the Vosges Mountains in the early 17th century. Between 1983 and 1993, 21 lynx were released during a reintroduction program. However, only 10 lynx survived notably because of illegal killings. Besides, tensions appeared between local stakeholders: the return of the lynx in the Vosges Mountains was not unanimously accepted. Almost 30 years later, the lynx is still critically endangered in the Vosges Mountains and acceptance remains still fragile. Thus, its conservation status needs to be improved urgently. This is a challenge for the species in the Vosges Mountains as well as for the Upper Rhine lynx metapopulation. In that context, a Regional Action Plan focusing on lynx in the Vosges Mountains has been written from 2016 to 2019 according a participative approach. A total of 18 actions answering to four topics (coexistence with hunters and breeders, ecological connectivity, monitoring, awareness) have been identified. The implementation phase of this action plan will occur during 10 years, from 2020 to 2029, to restore durably the lynx conservation status in the Vosges Mountains.

Historical context and current situation

The Eurasian lynx became extinct in the Vosges Mountains in the early 17th century (Stahl & Vandel 1998). The extinction causes are the same as for other European lynx populations: hunting, trapping, decrease of prey density and modification of habitats (Breitenmoser et al. 2003). During the 20th century, the evolution of European legislation gave way to a favourable ecological context for the return of the species (reforestation, increase in the density of prey, protection law). As in other regions of Western Europe, where a natural return of lynx appeared compromised or even impossible, a reintroduction program was organised in the Vosges Mountains (Vandel et al. 2006).

Between 1983 and 1993, a total of 21 lynx (9 females and 12 males) were released during 13 operations at 4 sites located in the Alsatian side of the Hautes-Vosges (Climont, Taennchel, Grand Ballon and Rossberg; Vandel et al. 2006). During these 10 years, 9 of the released lynx disappeared because of illegal killing (3 confirmed, 3 presumed), malnutrition (1), unknown causes (2), and 2 lynx were recaptured because too familiar with humans. Finally, only 10 lynx (4 f and 6 m) survived and thus, contributed to the establishment of the Vosges side of the Vosges-Palatinian lynx population (Vandel et al. 2006). In addition, during this reintroduction program, tensions appeared between the various stakeholders, particularly due to a lack of communication and concerted actions accompanying the lynx releases (Herrenschmidt 1990). As a consequence, this reintroduction program and so, the return of the lynx to the Vosges Mountains were not unanimously accepted. Then, the situation became even more fragile (Charbonnel & Germain 2020).

Almost 30 yeas later, the future of the lynx remains still uncertain in this part of its French range area. Indeed, after the reintroduction period, lynx regular presence area in the Vosges Mountains progressed reaching in

2004 a maximum of around 2,000 km2 (Marboutin 2013). From 2005, this regular presence area began to decrease until reaching its lowest value in 2016 with 100 km² (Marboutin 2013, Réseau Loup-Lynx 2014, 2016, 2019). In 2018 (01/04/2015–31/03/2018 period), it reached 400 km² spread over all the Vosges Mountains (Vosges du Nord, Vosges centrales, Hautes-Vosges and Vosges du Sud; Réseau Loup-Lynx 2019). All maps are available at https://carmen.carmencarto.fr/38/Lynx.map.

A lynx distribution map for the whole Vosges Mountains and neighboring mountains – notably from the Upper Rhine lynx metapopulation – for the biological year 2018–2019 was produced following the SCALP framework (Fig. 1; SCALP 2018/2019). Based on 10 x 10 km grid cells, the distribution in the Vosges Mountains was 1.400 km² (C1 and C2 categories), without any signs of reproduction.

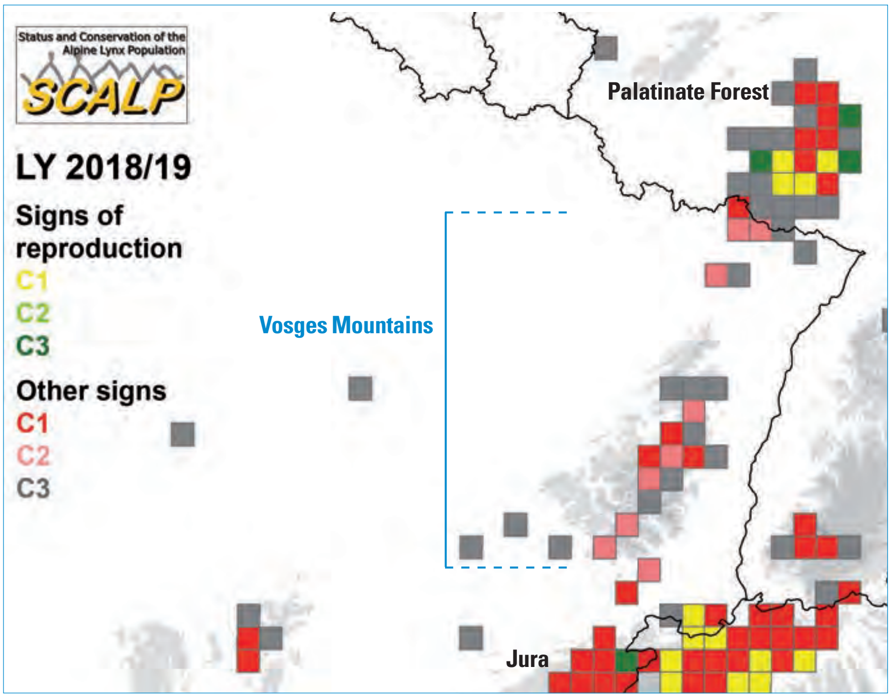

Fig. 1. Observed lynx distribution in the Vosges Mountains according to the SCALP monitoring report lynx year 2018/2019 (biological period: from 01/05/2018 to 30/04/2019) based on 10 x 10 km grid (SCALP 2018/2019). A distinction is made between different SCALP categories and eventual reproductive events (see Molinari-Jobin et al. 2021).

Lynx monitoring in the Vosges Mountains

One important aspect of the monitoring of the lynx situation in the French Vosges Mountains, is the development of different field monitoring procedures over time to answer questions of lynx conservationists fearing its decline. In France, lynx monitoring and conservation status evaluation are under the responsibility of the French Office for Biodiversity OFB, formerly French National Game and Wildlife Agency ONCFS, since 1988 and relies on 4,500 (status January 2021) trained volunteers with different background, so-called correspondents, forming the lynx monitoring network ("Réseau Loup-Lynx").

In 2013, the method to evaluate the lynx conservation status was newly reviewed for being more reactive (Réseau Loup-Lynx 2013). As the lynx is a discrete species and in order to avoid observation errors, the current method analyzes the abundance and recurrence of indices by successive and overlapping biennial periods of one year (Réseau Loup-Lynx 2013). These periods are fixed on the biological cycle of the species (for example from 1 April 2015 to 31 March 2017, and from 1 April 2016 to 31 March 2018 with 1 April 2016 to 31 March 2017 as overlapping year). The cartographic restitution of the regular and the occasional areas of lynx detected presence is produced annually according the 10 x 10km standard European grid (Réseau Loup-Lynx 2013). With this "overlapping biennial method", the decrease of the lynx regular presence in the Vosges Mountains is documented in 2005 whereas the previous method documented it only in 2011 (Marboutin 2013).

In parallel, different field protocols have been conducted since 2011 in order to clarify the conservation status of the lynx in the Vosges Mountains. During winters 2011/2012 and 2012/2013, two intensive tracking sessions have been organized in the regular presence area of lynx resulting only in nine signs of presence in the Vosges centrales (Donon sector) and one lynx track in the same area (Marboutin 2013). Besides, during winter 2012/2013, a lynx (named Van Gogh because of its right ear cut off) was photographed in the same sector thanks to camera traps placed in the field by volunteers from the Réseau Loup-Lynx (Germain 2013). Moreover, four intensive camera trapping winter sessions were organised from 2012 to 2016 in four different study areas (2012/2013: Hautes-Vosges, 2013/2014: south of A4 highway, 2014/2015: Vosges du Nord, 2015/2016: Vosges centrales). Each of them lasted two months, with around 400 km² study areas (grid with 2,7 x 2,7 km cells) and 50–60 camera traps (one site in every second cell, two camera traps per site). Camera sites were selected based on previous signs of lynx presence, local knowledge, and landscape features to optimize detectability. These camera trap sessions resulted in zero photo of lynx (Germain 2014, Germain et al. 2013, 2016, Charbonnel et al. 2017). In comparison, 92 lynx were identified from 2011 to 2015 in the French Jura Mountains with the same protocol applied to three study areas (Gimenez et al. 2019). At present, the lynx monitoring network enhances coordinated camera trapping in the Vosges Mountains, more particularly in the context of new lynx arrivals from the Palatinate forest where a reintroduction occurred from 2015 to 2021 (Schwoerer 2021, Scheid et al. 2021).

Challenges for lynx in the Vosges Mountains

The critically endangered conservation status of the lynx in the Vosges Mountains can no longer be questioned and its status needs to be improved urgently. This is a challenge for the species, not only at the scale of the Vosges Mountains, but also at the western European one and, more precisely, at the "Upper Rhine lynx metapopulation" scale (Palatinate Forest–Vosges Mountains–Jura Mountains–Black Forest). Indeed, by being located between the Jura Mountains, which host the main core of the French lynx population and is linked to the Swiss lynx population (Drouet-Hoguet et al. 2021), and the Palatinate Forest in Germany where a reintroduction program occurred (Idelberger et al. 2021), the Vosges Mountains occupy a strategic position for the connectivity of western European lynx populations.

Even if the ecological connectivity between Palatinate Forest, Vosges Mountains, Jura

Mountains and Black Forest remains currently far from optimal (Morand 2016, Zimmermann & Breitenmoser 2007), a natural colonisation of the Vosges Mountains by lynx may be possible, both, from the north and the south. For instance, from 2017 to 2021, five lynx (2 f and 3 m) released in the Palatinate Forest and four progeny (4 m) came to the Vosges Mountains. One female and four males installed their home ranges there, two males have a transboundary home range, and two lynx (1 m and 1 f) were observed only passing through (Idelberger et al. 2021, Scheid et al. 2021). In the same way, a male (lynx F25_034 also named Bingo) arrived in the south of the Vosges Mountains from the Doubs region during winter 2014–2015 where he was pictured by camera traps (Hurstel & Laurent 2016, Germain et al. 2017). Before dispersing, F25_034 had also been photographed more than 20 times north-west of Besançon (French Jura Mountains), from November 2013 to June 2014 (Source: Réseau Loup-Lynx / OFB data base). This was the first evidence of dispersal of the species from the Jura to the Vosges Mountains (Chenesseau & Briaudet 2016, Hurstel & Laurent 2016). Other lynx are detected currently or passed by in the Vosges centrales and in the Hautes-Vosges but their origin are unknow (Schwoerer 2021). In Spring 2021, a female from the Palatinate forest settled down in the Vosges du Nord gave birth to two young (M.-L. Schwoerer, pers. comm.).

The first regional action plan for lynx conservation in France

To respond to the urgent need of improving the lynx conservation status in the Vosges Mountains, the drafting of a Regional Action Plan PRA occurred from 2016 to 2019 (see Charbonnel & Germain 2020). The regional action plan for restoring the conservation status of the Eurasian lynx in the Vosges Mountains was first named "Programme Lynx Massif des Vosges". At this time, no National Action Plan existed for France, but in the continuity of Breitenmoser et al. (2003)'s action plan for lynx conservation in Europe, the PRA aims to define and develop concrete actions to restore durably the conservation status of the Eurasian lynx in the Vosges Mountains through a participative, concerted and shared process involving local stakeholders (hunters, sheep breeders, scientific, NGO, government agencies, etc.). A knowledge synthesis has identified five conservation needs and issues, ordered by priority:

1. Improving coexistence with human activities (hunting, livestock) to enhance lynx acceptance.
2. Restoring the ecological connectivity between mountain ranges (Jura-Vosges-Palatinate-Black Forest) and conserving a favorable habitat within the massif.
3. Reducing human-caused mortality (collisions with traffic and illegal killings).
4. Consolidating the network of observers and developing cooperation (regional and cross-border) for better monitoring and protection of the lynx.
5. Disseminating knowledge about the lynx and the issues of its conservation.

To address these needs and issues, governance and decision-making were based on a steering committee, a reading committee, five working groups ("Coexistence with hunting", "Coexistence with livestock", "Habitat and connectivity", "Monitoring and conservation", "Representations and awareness"), external advisors, and a coordination unit. Decisions were taken by consent in order not to look for the best/ideal solutions, but for decisions which respect the limits of those who will have to implement them, and which in no way compromise the capacity of the group to carry out its objectives (Charbonnel & Germain 2020). After three workshops with each working group, a total of 18 actions have been identified (Table 1). These actions are classified according to four topics ("Coexistence with human activities", "Habitat and ecological connectivity", "Monitoring and conservation", "Representations and awareness") – answering to the conservation issues and working groups themes – and three domains ("Study", "Protection and management", "Communication"). Each of these 18 actions are detailed in action sheets that specify its topic, its domain, its context, its objectives, its coordinators, its calendar, etc. During 10 years (from 2020 to 2029), the implementation phase of the PRA will be coordinated by the Regional Directorate for the Environment, Planning and Housing (DREAL Grand Est), and will occur within the consistency of the governmental National Action Plan (PNA) which is currently emerging.

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Table 1. List of the 18 actions of the regional action plan (PRA) for restoring the conservation status of the Eurasian Lynx in the Vosges Mountains (2020-2029). Topic: 1 = Coexistence with human activities (hunting and livestock), 2 = Habitat and ecological connectivity, 3 = Monitoring and conservation, 4 = Representations and awareness. Domain: S = Study, P/M = Protection and management, C = Communication.

Topic	Domain	N°	Title of the action
1	P/M	1	Consider the presence of lynx in hunting activities
		2	Support sheep breeders to improve coexistence with lynx
		3	Fight against illegal killing of lynx
	C	4	Communicate with hunters
		5	Communicate with sheep breeders
2	S	6	Refine knowledge about lynx habitat, corridors, and movement barriers
	P/M	7	Maintain, restore areas of favorable habitat and corridors
		8	Facilitate the crossing of linear transport infrastructures and reduce mortality
	C	9	Communicate on lynx habitat with managers, planners and decision makers
3	S	10	Monitor the evolution of lynx distribution with methods adapted to the Vosges Mountains
		11	Study the future of the lynx in the French Vosges Mountains and complement PRA actions
	P/M	12	Strengthen the regional/cross-border cooperation and boost the existing monitoring network
		13	Taking care of orphans and injured lynx
4	S	14	Identify, complete and evaluate studies on representations
	C	15	Strengthen awareness and communication projects around the lynx
		16	Value the image of the lynx and reinforce acceptation thanks to local development
		17	Continue and generalise concertation meetings with local stakeholders
	C	18	Coordinate and implement the regional action plan

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Reintroduction of Eurasian lynx in the Palatinate Forest, Germany

In the reintroduction programme in the Palatinate Forest – as part of the French/German biosphere reserve Palatinate Forest / Vosges du Nord – a total of 20 wild born lynx *Lynx lynx* from Swiss and Slovakian origin were released until 2020 to form a nucleus for the further expansion of the subpopulation. The reintroduction was accompanied by involvement of stakeholders, a management plan, environmental education, and public relations. Stakeholders, including hunters and livestock keepers, predominantly supported the reintroduction. The reintroduction has been indispensable to re-establish a subpopulation of lynx in its formerly natural range in the Palatinate Forest. The subpopulation will contribute to the conservation of the species, which is classified as critically endangered in the Red List of threatened species in Germany (Meinig et al. 2009) and is present in Germany and France only in few segregated, more or less isolated occurrences.

With the help of the European Union's funding programme LIFE, the Stiftung Natur und Umwelt Rheinland-Pfalz (SNU) and its project partners Landesforsten Rheinland-Pfalz, SYCOPARC in France and WWF Germany are implementing the project for the reintroduction of the Carpathian lynx in the Palatinate Forest, Germany. The reintroduction programme with translocation of 20 wild born lynx from Swiss and Slovakian origin started in January 2015 and will continue until September 2021. The EU LIFE programme co-finances 50% of the project costs of 2.75 million Euros. The Palatinate lynx occurrence will contribute to the protection and preservation of a species that only occurs in a few isolated areas in Europe (Breitenmoser & Breitenmoser 2008). The Palatinate Forest covers 1,790 km² of forests and is considered to be the largest coherent forest in Germany. 360 km² of the area are protected as Natura 2000 sites. The area is part of the transboundary UNESCO Biosphere Reserve Palatinate Forest / Vosges du Nord, covering a total area of 3,028 km².

Several feasibility studies conducted on behalf of the state Rhineland-Palatinate documented the suitability of the Palatinate Forest in connection with Northern Vosges for a reintroduction of the lynx (Van Acken 1977, Wotschikowsy 1990, ÖKO-LOG 1998). An active release of the lynx to the German part of the Biosphere Reserve Palatinate Forest / Vosges du Nord was recommended (ÖKO-LOG 2010) as natural immigration of lynx into the Palatinate Forest had not been documented in the last decades and had not been expected due to the conservative dispersion behaviour of the species. However, lynx released in the Palatinate Forest may disperse to the Northern Vosges and will ultimately enable genetic exchanges with the Southern Vosges (FR), the Jura Mountains (FR/CH) or, across the Rhine River, even with the Black Forest (DE) (Fig. 1).

Fig. 1. Palatinate Forest and neighbouring extant or potential lynx habitats and dispersal opportunities. Dispersals were documented from Jura to Vosges (Drouet-Hoguet et al. 2021), from Jura to the Black Forest (Herdtfelder et al. 2021) and Palatinate Forest to Vosges (see text).

Preparatory phase

The acceptance of the lynx in the local society has been generated slowly and steadily over years. Authorities and the civil sector acted jointly over a long period of time and generated a positive appreciation towards the lynx. In the release area Palatinate Forest approx. 60% of the land is owned by the state, 30% by municipalities. The state and all nine local municipalities in and adjacent to the Palatinate Forest welcomed the reintroduction.

The local population and all relevant interest groups have been informed and consulted before the project started. The reintroduction programme provided for well-designed reporting and public relation activities during the releases and subsequent monitoring. Staff of the project visited local meetings of hunters and livestock owners on a regular basis and gave talks about the project. The direct exchange with people was a very important task. This allowed installing continuous feedback and improvement in the work of the project building up trust between all parties. To ensure that the acceptance work is favourable, in addition to several information events, a wide variety of materials have been compiled which provide interest-group-specific information surrounding the topic of the lynx. In particular, the Rhineland Palatinate Hunting Association (Landesjagdverband Rheinland-Pfalz) is actively supporting the project communications.

Within the communication platform "Parliament of the lynx" regional spokespersons of livestock farming, hunting, forest, nature conservation, tourism, public authorities, and associated institutions were regularly informed on the current status of the reintroduction and were invited to the exchange of opinions and to develop joint resolutions on future developments or research needs. The parliament was meeting in two separate chambers, one in the Palatinate Forest, the other in the Northern Vosges Mountains. Once a year both chambers met jointly. A comprehensive monitoring programme has accompanied the resettlement. The data gathered in the monitoring programme includes occurrence, distribution and behaviour, and the reports were included into the participative processes with the various interest groups. The "Parliament of the lynx" has itself established as an interest-spanning institution, which is recognised and actively participating in the adjustment of the project. The open and direct communications have helped to develop a basis of trust between all of the parties, and to both anchor and strengthen the acceptance for the lynx and the reintroduction project.

A management plan for the handling of lynx in Rhineland-Palatinate had been published before the release of the first lynx (MUEEF 2016). It covers aspects of demographic monitoring, proposed solutions in case of conflicts, prevention and compensation measures, rules for conflict management and responsibilities. The regulations were adopted in consensus with the stakeholders and can be changed jointly if the situation requires.

A German-French homepage as a pivotal communication platform was implemented with regularly updated information about the development of the project, current events and a monthly updated map showing the approximately range of the lynx in the transboundary biosphere reserve and its surroundings. The large attendance of the homepage showed the relevance of this information for the public. Through the incorporation of local institutions and schools, the provision of environmental education materials and the education of so-called regional lynx consultants, multipliers have been given training with the effect of raising the levels of awareness in the public for the project objectives. For school classes, the environmental education programme "Eye of the Lynx" has been established, which allows children to look at the return of the lynx to their former habitat on an intensive and creative basis.

The Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Prof. Schraml, conducted a survey of the acceptance of the lynx in the Palatinate Forest in the context of a bachelor thesis (Fräger 2016). More than 300 respondents of the telephone survey had a predominantly positive attitude towards the lynx. 70% of the interviewees said they had a positive or very positive feeling about the lynx; only 1% expressed negative feelings. More than 55% of the interviewees mentioned only advantages when asked about the advantages and disadvantages of reintroduction. About 10% view the presence of the lynx critically, mainly people who were afraid about negative consequences for the tourism.

In addition and in order to examine the idea of establishing the lynx as an image carrier of the Palatinate Forest Biosphere Reserve, an assessment of the lynx's tourism potential as an attractor for the region was carried out (Sigmund 2017). In cooperation with the Pfalz.Touristik e. V. a bachelor thesis was developed under the supervision of Prof. Bachinger, from the University of Applied Sciences Rottenburg. The thesis concluded that lynx can create values for the sustainable tourism in the Palatinate Forest and offers corresponding potential. In an online survey the guests showed great interest in the lynx in the Palatinate Forest. Guests would be willing to extend their holidays by two days on average because of the presence of the lynx. For lynx-specific offers guests would invest about 18–20 Euros. In comparison to other (wildlife) offers, the challenge for the lynx and its secret way of life lies in an appealing offer development.

Table 1. lynx translocated into the Palatinate Forest (2016 – 2020), state May 2021. Country of origin SLK = Slovakia, CH = Switzerland. * orphaned lynx.

Released	Origin	Lynx	Sex	Born	Fate
2016	SLK	LUCKY*	m	2015	dead (May 2019, car accident)
2016	SLK	KAJA*	f	2013	last record June 2020
2016	SLK	LUNA*	f	2011	last record April 2017
2017	CH	ARCOS	m	?	migrated to the Southern Vosges, last record November 2020
2017	CH	BELL	f	2013	migrated to the Donnersberg, last record September 2019
2017	CH	ROSA	f	2012	last record January 2021
2017	SLK	CYRIL	m	~ 2011	last record June 2019
2017	SLK	LABKA*	f	2016	found dead (February 2018, train accident)
2017	CH	ALOSA*	f	2016	euthanized (February 2018, infected paw)
2018	CH	JURI	m	2016	found dead (February 2020, infection)
2018	CH	JARA	f	2012	last record December 2018
2018	SLK	WRANO*	m	2017	last record August 2020
2018	SLK	ALFI*	m	2017	last record May 2021
2019	CH	MALA	f	2010	last record May 2021
2019	CH	GAUPA	f	2012	last record March 2021
2019	CH	LIBRE	m	2016	GPS-collar active
2019	SLK	BRAŇO	m	2017	last record June 2020
2020	CH	ISIS	f	2017	last record April 2021
2020	CH	LYCKA	f	2011	GPS-collar active
2020	CH	TARDA	f	~ 2018	last record March 2020

Releases and post-release monitoring

The partners from the countries of the lynx donor population Slovakia (DIANA, Zoo Bojnice) and Switzerland (KORA, FIWI) and the project coordinator and partners in the receiving country Rhineland-Palatinate (SNU, MUEEF) agreed in a Memorandum of Understanding to defined procedures and protocols for the translocations. The rules of transport, quarantine, necessary veterinary medical examinations, preventive measures, exclusion criteria for transport and release were fixed before the start of the translocations. The purpose was to guarantee a smooth and coordinated operation of the translocation project. The determination of a reintroduction plan, as well as capture and release protocols enabled all partners to act in a concerted way and to fulfil all necessary regulations of the different legislation between the countries and to conform to international standards (e.g. IUCN, IATA, CITES). The handling of the lynx respected the best practice experience. The animals had to be surveyed during capture, quarantine and transport, and received medical treatment whenever required by experienced veterinarians. Reasonable precautions for possible emergency cases were established. Health requirements were fixed, e.g. tests, tolerable versus intolerable pathogens (as FeLV, FIV) and possible non-infectious problems. The quarantine time in Switzerland lasted between five and eleven

Fig. 2. Female TARDA from the Swiss Jura Mts, the last of the 20 lynx released in the Palatinate forest in 2020 (Photo A. Prüssing, SNU).

days, whereas the quarantine time in Slovakia varied between three and five weeks, respecting the need of antibody-titre of rabies. The partners reviewed the situation and the release strategy several times during the implementation of the translocations and optimised them if necessary.

Based on monitoring results, the donor countries defined capture areas with the numbers of possible captures regarding to the sex of the animals to ensure that translocations do not threaten the donor population. Main capture season was from February to beginning of April to avoid the early separation of juvenile lynx from their mothers or the capture of pregnant females in late stages. Lynx were set free in a "hard release", that is immediately after arrival in the release area and final (health) check. All released lynx were equipped with GPS/GSM telemetry collars e.g. Lotek Wildcell SL or SD and a mechanical drop-off (predetermined breaking point made of wire). The GPS tracking collars allowed the monitoring of the spatial behaviour, findings of prey and the development of the reintroduction process.

Supplementary monitoring methods were established to evaluate the development of the population. A genetic monitoring was performed to build up a pedigree and to be able to evaluate the development of the genetic variability within in the new subpopulation on the long term. An extensive opportunistic monitoring was expanded including a network of trained field-experts to collect and verify lynx-indications from the public and to gain additional information about appearance and distribution. This was needed especially for the time, when the different GPS collars stopped data transfer after the end of their operating time (1–2 years) and for non-collared offspring. A systematic camera trapping has been conducted in the last two winters of the project to estimate the size of the population. The overall result of the two runs is imminent.

With the reintroductions from July 2016 to March 2020 a total of 20 lynx (12 female, 8 males) have been captured and relocated with the help of the origin countries' partners and authorities. Twelve lynx were captured in Switzerland (Fig. 2), eight originated from Slovakia, of which seven were orphans temporarily held in captivity. Until the end of April 2020 there had been four documented losses of released lynx due to (traffic) accidents (Table 1). The lynx showed their physical capacities and adaptability on various occasions. One male (ARCOS) migrated to the Higher Vosges Mountains covering a distance of approx. 350 km in one month. Another male (CYRIL) took the liberty to cross the river Rhine (width about 200 m) close to the industrial areas of Mannheim and Ludwigshafen. He was captured and brought back to the Palatinate Forest, because the landscape on the other side of the Rhine was heavily fragmented through streets and settlements and other lynx population have not been accessible. After his relocation CYRIL stayed in the Palatinate Forest. Major parts of the transboundary Biosphere Reserve and also beyond have been explored by lynx (Fig. 3).

Reproduction success

The first two cubs were already observed in 2017. The young male lynx LUCKY took already part in the reproduction in his second year of life. Three more litters followed in 2018 and two litters each in 2019 and 2020. Reaching a total documented offspring of at least 16 cubs for the first four years (Fig. 4). More litters are possible. Preliminary results from monitoring might suggest not yet (genetically) detected additional lynx in Rhineland-Palatinate too.

Verifiably seven individuals out of 20 released lynx took part in reproduction until 2020, three of the 20 were just relocated in spring 2020. Two litters are from Swiss-Slovak lynx pairings, while two litters were from already pregnant translocated females from Switzerland, bringing in additional genetic material beside the releases. Three Lynx couldn't take part in the reproduction due to prompt spacious migration or death (ARCOS, LABKA, ALOSA). A contribution to the reproduction of the other lynx remains open. Remarkable is the high number of male cubs (verifiably eight males to two females) in the project, from six cubs the sex is still unknown. Den sites were inside rock caves or under logging residues. Although forest roads were close by, there were low human activity or the access to the den was difficult.

Prey

A random, unsystematic search of kills has been conducted with the help of collected GPS-data. Among 205 registered kills of wild animals, the main prey of lynx was roe deer (82%), followed by red deer (7%) and fox (6%). Mouflon, marten, hare and wild boar was killed as well. This is similar to other studies in Germany (Mayer et al. 2012).

Eleven attacks on livestock happened in eight different places, sometimes flocks or enclosures were affected twice shortly one after the other. Killed species were sheep, goats, respectively fallow and red deer in enclosures. The livestock owners were compensated for the losses. Prevention measures like electrification of fences were paid and the owners implementing those measures received support in the field from the staff of the project and a network of volunteers.

Preliminary results and conclusions

A notable aspect in the project is the integration of orphaned lynx in the reintroduction. This procedure allowed a faster establishment of the new lynx subpopulation, because capture success in the wilde can partly depend on random incidents. A fast population growth fosters the genetic diversity within a new population (Frankham 2009). The first releases in 2016 were realised with three orphans from Slovakia. The lynx were held in captivity for different time spans. At the date of the release the individuals were 1 (M), 3 and 5 (both Fs) years old. The three lynx explored their new surrounding quite cautiously. It appears that the cautiousness facilitated for the three animals to stay in touch, which helped to increase the chances of mating and to establish a first nucleus of a lynx subpopulation in the greater area of the release site. All following releases took place at approximately the same site to allow translocated lynx to recognize the presence of lynx in their new habitat. Main background for this procedure was to avoid migration into areas outside the Palatinate Forest and to expand the newly established nucleus. Most of the released lynx established their territories in this nucleus. Apparently, three of the non-orphaned lynx started spacious excursions directly after release, leaving the populated area within a very short time, while the orphaned lynx explored the area in a more conservative manner. Otherwise, there might be a higher probability of early losses with unexperienced subadults (e.g. death of LABKA through train collision shortly after release). The ability to catch and kill prey seemed not to be a problem for the orphaned lynx; most of them killed roe deer successfully after a short period of time. The scientific analysis of the data is not completed yet. Further research on this topic may help to evaluate the suitability of orphans for introductions or reinforcement projects.

In conclusion, the major objective to establish a first nucleus of a lynx subpopulation in the Palatinate Forest has been achieved. Major parts of the Palatinate Forest have been populated by lynx, parts of the Northern Vosges too. A first home range in the north of the Palatinate Forest was established (BELL). The observed migrations of male and female lynx (ARCOS, LIBRE, KELY, LYCKA) documented the possible exchange between the Northern and the Southern Vosges Mts. The successful passing of the migration barrier at the Col de Saverne, the narrowest passage of the Vosges Mountain with crossing of highway, express railway line and water canal, was questioned before by many people. This was an important signal for the possibility of a natural dispersal of lynx between the subpopulation in the Upper Rhine metapopulation. Now the lynx occurrence in the Palatinate Forest offers another link for migrating lynx originating from all geographic

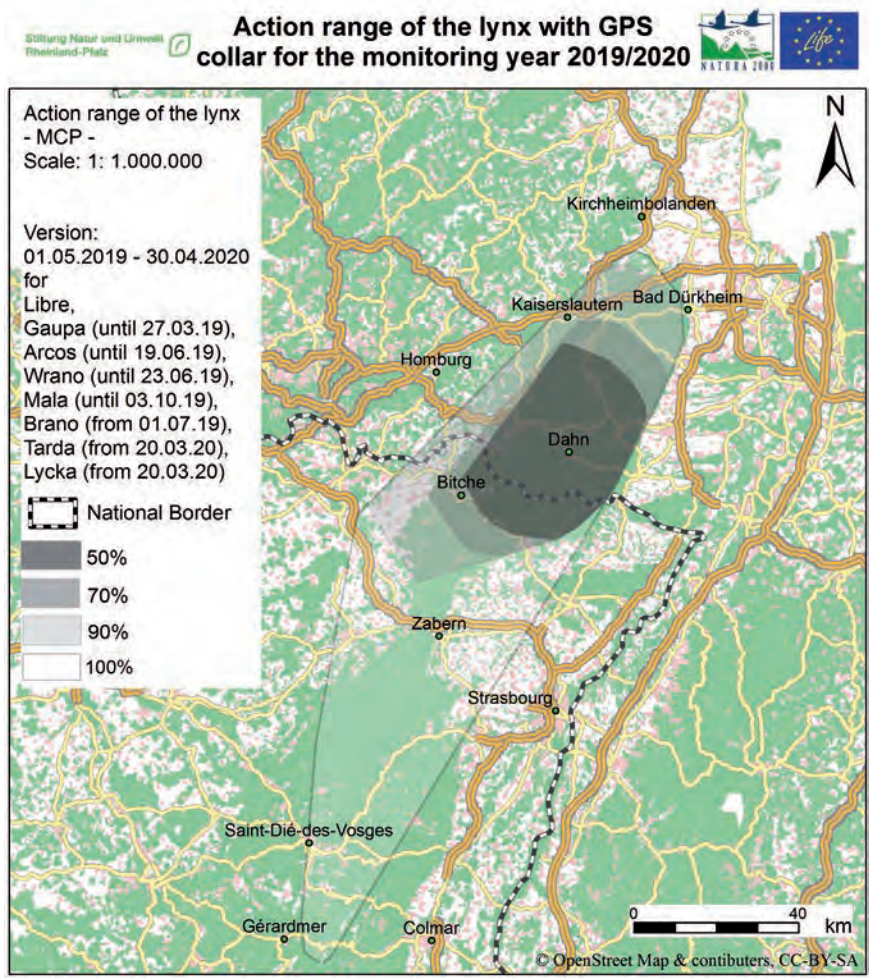

Fig. 3. Combined action range of 8 GPS-collared lynx in the Palatinate Forest, presented as MCP (minimum convex polygon) for the monitoring year 2019/2020, © SNU.

Fig. 4. Two cubs of female ROSA documented in Palatinate Forest (Photo B. Allmoslöchner).

Table 2. Offspring in the Palatinate Forest (2016–2020), status May 2021.

Cubs (name)	Year	Mother (country of origin)	Father (country of origin)	Sex of cubs	Fate
1 (PALU)	2017	KAJA (SK)	LUCKY (SK)	m	last record January 2020
2 (FILOU)	2017	KAJA (SK)	LUCKY (SK)	m	last record April 2021
3	2018	JARA (CH)	unknown Swiss lynx	m	last record June 2018
4	2018	KAJA (SK)	unknown	unknown	last record September 2018
5 (FRAN)	2018	ROSA (CH)	LUCKY (SK)	1x m, 1x unknown	last record March 2021
6 (FIFO)	2018	ROSA (CH)	LUCKY (SK)		last record March 2021
7 (RUMO)	2018	ROSA (CH)	LUCKY (SK)	m	last record April 2021
8 (PIP)	2019	MALA (CH)	WRANO (SK)	2x m, 1x unknown	last record April 2020
9 (TWIK)	2019	MALA (CH)	WRANO (SK)		last record April 2020
10 (KELY)	2019	MALA (CH)	WRANO (SK)		last record March 2021, migrated to S Vosges
11	2019	GAUPA (CH)	prob. unknown Swiss lynx	m	last record December 2019
12	2020	ROSA (CH)	unknown	f	last record November 2020
13	2020	ROSA (CH)	unknown	f	last record November 2020
14	2020	ROSA (CH)	unknown	unknown	last record November 2020
15	2020	GAUPA (CH)	unknown	unknown	last record July 2020
16	2020	GAUPA (CH)	unknown	unknown	last record February 2021

directions. Nevertheless, the newly founded lynx nucleus is still small and fragil. The success of the reintroduction depends on further offspring especially female, and contribution of as much as possible of the released lynx in the reproduction for genetic variability in the long term.

Further conservation efforts will focus on the further growing of the subpopulation, demands of genetic variability, sufficient opportunities for dispersal to adjacent subpopulations, maintaining a high-acceptance, establish a permanent management and a common management of the Upper Rhine metapopulation (Krebühl et al. 2020).

For further information visit www.luchs-rlp.de

Acknowledgements

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The return of lynx to north-western Poland

Although the lynx *Lynx lynx* has been eradicated in north-western Poland several hundred years ago, the currently conducted analysis of habitat suitability shows that in this part of Poland there are habitats suitable for lynx and prey populations no smaller than in the eastern part of the country. The plan for the reintroduction of the Eurasian lynx to western Pomerania is implemented by the Western Pomeranian Natural Society and financed under the Infrastructure and Environment Program 2014-2020. The approach is to use a combination of soft release of captive-born lynx and possibly translocation of wild lynx from the north-east European lowland population.

The Eurasian lynx has been eradicated several hundred years ago in north-western Poland (Bieniek et al. 1998). During the whole 20th century the range of the species included only the eastern and southern part of the country with a clear gap between the northern (Baltic population) and southern (Carpathian population) parts of its distribution in Poland. Farther restrictions of its occurrences were recorded in the 1960s and 1980s due to overhunting, when the species survived only in a few forest patches adjacent to the eastern border of the country. Beside of a few occasional wanderings the lynx has never been able to establish the population west of the Vistula River. Even after 1995 when it became a strictly protected species its range has not increased (Mysłajek et al. 2019). A habitat suitability analysis conducted by Huck et al. (2010) have shown that forested areas potentially suitable for lynx are still available in the western part of Poland, although habitat fragmentation by un-forested areas and major roads may constitute a barrier for successful dispersing. On the other hand, a genetic study conducted in north-eastern Poland confirmed that this population of lynx is characterised by lower variability than that from intensively forested areas of Estonia and Latvia (Schmidt et al. 2009). In addition, significant genetic differences were found (both in microsatellite genotypes and mtDNA haplotypes), which indicates reduced level of gene flow between these populations (Ratkiewicz et al. 2014), which may result from the existing environmental isolation between these areas. These facts suggest that unfavorable processes are currently affecting lynx in Poland that may be attributed to its location at the peripheral parts of the species range and habitat fragmentation. Therefore, active conservation measures are necessary to influence both the extent of the area inhabited by the lynx and its genetic variability to increase the viability of the population.

Two reintroduction programs to expand the lynx distribution area and thus to enhance the lynx conservation in Poland took place so far. The project with captive born individuals was conducted in 1993– 2000 in central Poland in Kampinos National Park located in the vicinity of the country capital – Warsaw (Böer et al. 2000). It is likely that lynx are still surviving and reproducing there, as their presence was recorded by photo-trapping in 2018 (Mysłajek et al. 2019). Another reintroduction project was conducted in north-eastern Poland in the Piska Forest over the years 2012– 2015 – the area where lynx population was extirpated by overhunting in the 1980s (Jakimiuk 2015). While the Kampinos project was conducted along the western bank of the Vistula river, having thus little opportunity for reinforcement through immigrations from the eastern natural populations, the Piska Forest lies within the range of the former north-eastern meta-population. If both projects will appear successful, they are however insufficient to warrant enhancing sustainability of the lynx within the territory of Poland. More population nuclei should be established to expand the species range and increase its population size. Due to the high fragmentation of habitats in Poland, and especially the large discontinuity of the forest cover along the Vistula valley, crossing the country from south to north, it is very unlikely that lynx could spontaneously inhabit western forests in foreseeable time. It is thus important to make efforts for the lynx return into the areas where it was extirpated long ago.

We have selected an area for lynx reintroduction in forests of Western Pomerania of Poland based on habitat suitability analyses conducted with use of the CORINE land cover maps (Huck et al. 2010) and additionally with use of a Digital Database of State Forestry that included data on detailed habitat structure and prey availability (Górny et al. 2017). High forest cover (44%), low fragmentation (2.37%) and a sparse road network (main and secondary roads with 0.08 and 0.10 km/km^2, respectively) create conditions suitable for restoring the lynx population. An additional advantage is the high availability of the food base (720 kg/km^2) due to the high numbers of roe deer and red deer. Four potential areas were selected within Western Pomerania: Barlinek Forest, Smolarz Forestry, Drawno Military Compound and Mirosławiec Forestry (Fig. 1).

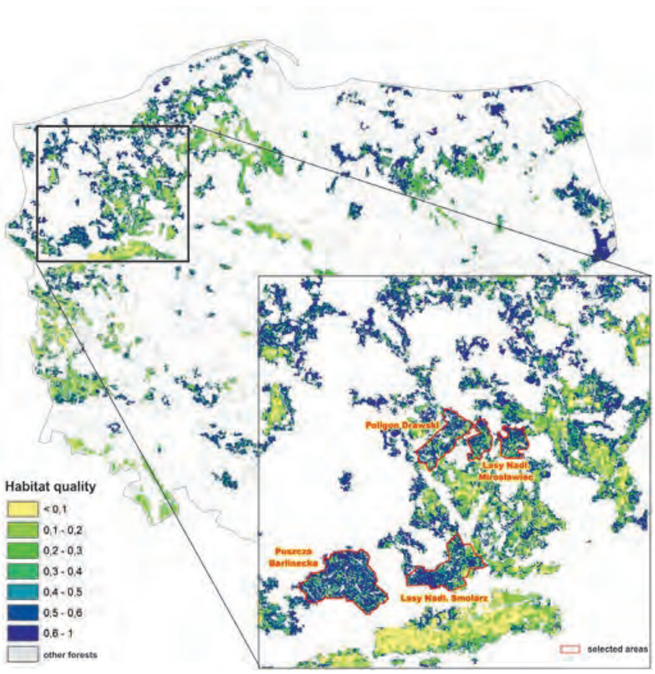

Fig. 1. Areas selected for lynx reintroductions in western Poland based on habitat suitability analysis..

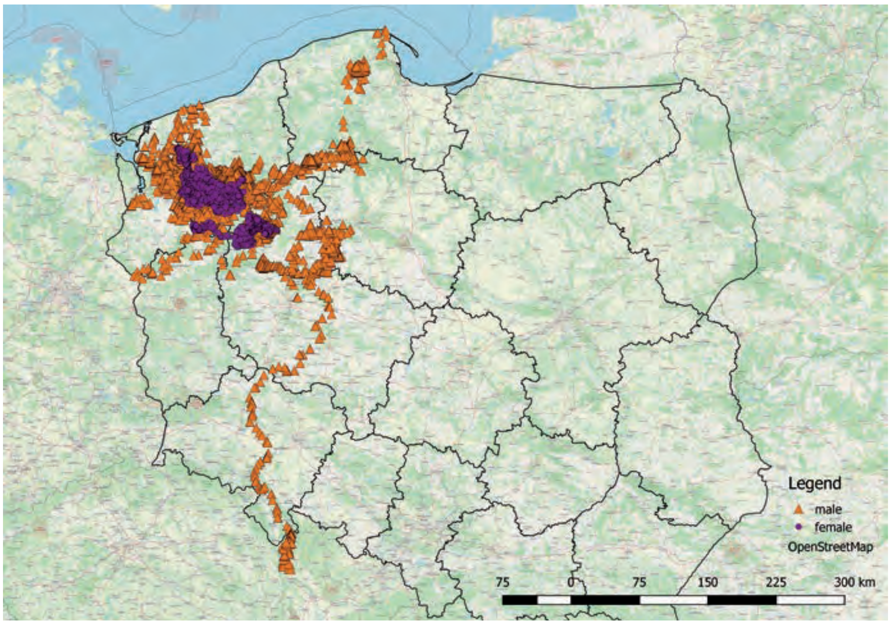

Fig. 2. Combined movements of 38 still living in Poland GPS-collared lynx released between 2019–2021 within the framework of reintroduction program. Two lynxes emigrated to Germany, the female definitely lives in Germany, there is no information about the male.

The plan for the reintroduction of the Eurasian lynx to western Pomerania has been implemented by the Western Pomeranian Natural Society and financed under the Infrastructure and Environment Program 2014–2020. The approach is to use a combination of soft release of captive-born lynx and possibly translocation of wild lynx from the north-eastern European lowland population, but also importing individuals from breeding centers. During the project five breeding and adaptive enclosures have been built. The lynx are bred in captivity, trained for hunting wild prey and released. It is aimed that the lynx used in the program are of Baltic population origin. Either blood or hair samples are collected from all individuals and genotyped for 20 autosomal microsatellite loci coupled with control region (mitochondrial DNA) sequencing. Breeding is only allowed for pairs of genetically proved Baltic origin and unrelated individuals. Before releasing, the lynx are fitted with GPS (280 g) collars.

Sixty-one lynx (26 females, 35 males, including 59 individuals imported from the breeding centers and 2 born in captivity) were released until July 2021. Fifteen lynx (24.6%) did not survive due to vehicle collisions (4), diseases (8, mostly mange), predation (1) or unknown reasons (2). Another six are missing due to lack of GPS contact. All the remaining animals have well settled in the field and are efficient hunters. They are very rarely observed by people. The majority of individuals spread and established home ranges within the radius of 100 km from the release sites and only few males attempted longer explorations across the country. All females showed clearly restricted movements as compared to males (Fig. 2, data in preparation). We recorded nine certain cases of reproduction of lynx released into the wild. Two females gave birth twice in two consecutive years. There were from 2 to 4 kittens per litter (2.4 on average). The project is continued.

The results of the population viability analysis conducted with Vortex software (Górny et al. 2017) suggest that in the case of a successful reintroduction of lynx under the current project, one should ultimately strive to maximize the size and distribution of the population so that most of the forest environments available in Pomerania are occupied. All habitats together, useful for lynx in this area, characterised by large numbers of forest complexes connected by a network of numerous forest corridors, and at the same time by a large abundance of good quality habitats and high densities of ungulates can constitute a biotope for at least 80 individuals of this species. Such a population of lynx guarantees the survival of 100 years at the level of 57% if isolated (Górny et al. 2017). Therefore, it may still need to be managed.

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Steps towards a lynx population in the Black Forest?

The discussion between different stakeholders about a reintroduction of the lynx *Lynx lynx* in the Black Forest has been going on since the 1980s. Since the installation of the Working Group Lynx Baden-Württemberg (WG lynx) in 2004, the knowledge about the lynx and the conflicts behind it has been improved and distributed for all stakeholders represented in the WG lynx. The joint development of a technical concept for dealing with the lynx helped to develop concrete solutions for identified concerns of the stakeholders. After the state elections in spring 2021, the governing parties stated in their coalition agreement that the chances for the return of the lynx should be improved through a reinforcement program to support the population in close cooperation with all stakeholders concerned.

Baden-Wuerttemberg BW and especially the Black Forest is located less than 20 kilometres from the lynx population in the Jura Mountains and about 40 kilometres from the lynx population in the French Vosges Mountains. Together with the Palatinate Forest, these four low mountain ranges form the core of a potential Upper Rhine lynx metapopulation (Krehbuehl et al. 2021). Suitable habitats hosting existing subpopulations and largely unused habitats in the Black Forest are separated by the Rhine River Valley and the extensive human infrastructure that dissects it. Monitoring in BW shows dispersal of male lynx from the Jura to the Black Forest and adjacent regions, but females apparently avoid crossing this landscape (Fig. 1, Monitoring results of the FVA).

Since the 1980s, the reintroduction of lynx into the Black Forest has been discussed very emotionally by the stakeholders involved. The process was characterized by unilateral actions of opposing groups to defend their respective interests. At some point, lynx advocates went to court to fight for their right to reintroduce lynx on their own. In 1997, they suffered a major defeat, as the court ruled that reintroduction required the approval of the authoritative Ministry of Rural Areas, which the latter refused. The way the debate was conducted led to mistrust between the groups involved and to an escalation of the conflict (Luechtrath et al. 2012).

In 2004, a Working Group Lynx (WG Lynx) was established by the same ministry. One goal was to build trust and mediate between the stakeholder groups represented. External facilitation is used for this purpose. Since 2004, many actions have been discussed and implemented by the members of the WG Lynx (e.g. implementation of SCALP categories for monitoring, ensuring transparency of monitoring data, training local contact persons in monitoring and knowledge transfer, establishment of compensation funds for killed livestock).

From 2008 to 2012 the WG Lynx participated in the research project "Lynx in Baden-Wuerttemberg" conducted by the Forest Research Institute BW (FVA) in cooperation with the University of Freiburg to establish a common knowledge base. The results show that habitat suitability in the Black Forest is almost as good as in the Swiss Jura Mountains, but without the release of females, there is little chance to establish a viable (sub-)population in BW (Herdtfelder 2012). The results also show that the conflict about the lynx has to be seen as part of a larger conflict about the definition and ranking of societal values between the groups involved (Luechtrath 2011). One important effect of the research project and the deliberately neutral and all-party moderation of the WG is an increasingly respectful and appreciative interaction among the members of the working group, which could be observed over time.

As a consequence, a follow-up project was conducted from 2012 to 2016 by the FVA and other members of the WG Lynx to improve and distribute knowledge about lynx and now also wolves *Canis lupus* as well as knowledge about interactions and communication between members of affected groups in BW. During the project, local networks of stakeholders were established in three model regions and over 60 events were held at different spatial and organizational levels. At each event, information about conflict dynamics and strategies to improve communication were an important part of the presentations and discussions.

As a next step, in 2018 the Ministry of Rural Affairs engaged the FVA to prepare a detailed

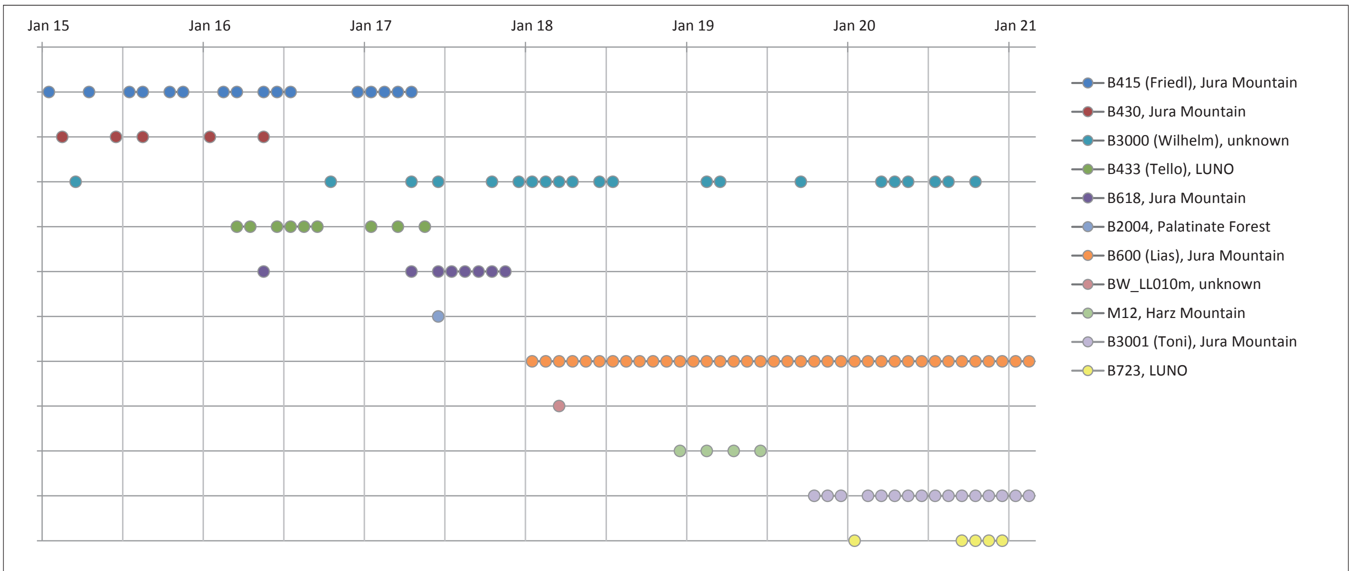

Fig. 1. Overview of lynx individuals identified in Baden-Württemberg over time, including information on the origin of each animal, all males.

concept that includes the current situation of lynx, the state of research, and the resulting options for the future management of lynx in BW. The members of WG Lynx participated in the development of the concept, especially in search for solutions that avoid or compensate perceived disadvantages for landowners, livestock keepers and hunters. A draft of the concept was completed in summer 2019 and included the following three alternative management scenarios: 1) status quo – no specific actions to improve the status of the lynx in BW; 2) small reintroduction project – reinforcement using only four female lynx within the next three years; 3) large reintroduction project – reinforcement using 12 lynx (eight females and four males). For all scenarios, the preparation of a management plan would be mandatory. Following the presentation of the complete draft concept to the WG Lynx, stakeholder groups had the possibility to send their final comments to the Ministry. In a high-level meeting of the WG Lynx held in October 2019, the ministry expressed the political will to implement a reinforcement project in cooperation with hunters and landowners. However, due to the ongoing debate about the general alignment with agriculture and nature conservation and the associated challenges for landowners, the ministry considered the timing inappropriate for an immediate implementation. To keep the process ongoing, the FVA was tasked with further clarifying practical challenges of a reinforcement project and supporting a continuous constructive dialog between stakeholders. After state elections in spring 2021, the old and new governing parties stated in their new coalition agreement that the chances for the return of the lynx should be improved by a reinforcement program to support the population, in close cooperation with all stakeholders concerned.

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The contribution of stepping-stone releases for enhancing lynx distribution

Assuming that large-scale reintroduction projects within the Alps or anywhere else in Western or Central Europe will be difficult to implement in the future, the stepping-stone approach to connect small and isolated populations seems an adequate strategy. Experiences indicate that the number of animals released in the frame of an adaptive release strategy (monitoring and further releases if needed) as well as distance to the nearest lynx population might be the crucial elements defining the success of these small-scale reintroductions.

"A raised stone used singly or in a series as a place on which to step when crossing a stream or muddy area" is the definition of stepping-stone. Figuratively, it can be defined as an action helping to make a limited, one-step progress towards a specified goal. In the context of lynx conservation, stepping-stones are defined as disconnected small occurrences that potentially connect otherwise isolated populations. Long-term viability of reintroduced lynx populations depends on the successful establishment of a large metapopulation, ideally connected with the Carpathian founder population. The Alps play a crucial role due to their large size and range, potentially connecting populations in Western and Central Europe (von Arx et al. 2021). However, the Alpine lynx population itself is far from reaching its potential extension and abundance and cannot be considered viable. Presently, the population consists of four subpopulations (Fig. 1): (1) The north-western Alps population is the largest one with its centre in western Switzerland, spreading into France and occasionally Italy. It originates from reintroductions in the 1970s. (2) In 2001 a first stepping-stone was created in north-eastern Switzerland with the one explicit aim to further the expansion of the Alpine population. (3) The second stepping-stone population was established based on the presence of one single male present in the Limestone Alps, Upper Austria. (4) The south-eastern Alpine lynx population originates from immigration from the Dinarics (Molinari 1998), where in 1973 six lynx were reintroduced (Čop & Frkovic 1998). The Dinaric lynx population initially thrived and expanded soon into the Alps and southwards to Bosnia and Herzegovina. However, during the past 20 years, the trend reversed (Fležar et al. 2021, Sindičić et al. 2013) with the consequence that the lynx in the south-eastern Alps is at the brink of its second extinction. The populations in the north-western Alps and in eastern Switzerland are about to merge. However, between these populations and the occurrences in the eastern Alps is a gap of unoccupied, although suitable habitat of 300 and 150 km, respectively (Fig. 1; Zimmermann 2004, Molinari-Jobin et al. 2018). Compared to wolf and brown bear, lynx populations spread slowly and do not easily overcome barriers. Although the individual dispersal capacity especially of male lynx is considerable, successful reproduction (and hence the spread of the population) requires a land tenure system with adjacent individual home ranges, allowing close contact to neighbouring conspecifics (Zimmermann et al. 2005). Nevertheless, during the past 20 years, the Alpine population has expanded its range by an average of 4% per year (Molinari-Jobin et al. 2018). The expansion was however to a large part due to stepping-stone projects. Our aim is to share experiences gained in the Alps and evaluate the significance of stepping-stone projects, discuss advantages and pitfalls, as well as future perspectives.

In the early 2000s the LUNO project was launched with the aim to improve lynx distribution in Switzerland (Robin & Nigg 2005). 2001–2003 a total of 9 lynx were translocated from the north-western Alps and the Jura Mountains to north-eastern Switzerland (Ryser et al. 2004). The lynx released soon established the typical land tenure system. The first cubs were reported one year after the first releases. Some outstanding events deserve to be mentioned: Male lynx TURO – likely on his attempt to return to the Jura Mountains, where he came from – crossed several highways and the Rhine River, before he was recaptured and rereleased. After his capture and rerelease, in a second attempt of homing, TURO became famous as he ventured into the city of Zurich. He did not succeed in crossing the city but stayed for several months in the city forest that provided plenty of roe deer, before he finally established a home range in the release area. The female AIKA crossed two highways and the river Reuss (Ryser et al. 2004). She spent the rest of her life without contact to other lynx. Female AURA never reproduced. Male ROCO established a territory but disappeared a few months after the release. His home range was soon taken over by male ODIN. Male VINO died in May 2003, resulting in the presence of only one adult male, ODIN, as TURO was not in contact with other females at the time (Ryser et al. 2004). After monitoring based on camera-trapping had revealed this unfavourable situation, it was decided to reinforce the occurrence with another three lynx in 2007–2008. This input boosted the stepping-stone population, which started expanding south-and eastwards. Reproduction was observed east of the Rhine River in Liechtenstein and Vorarlberg, Austria. The

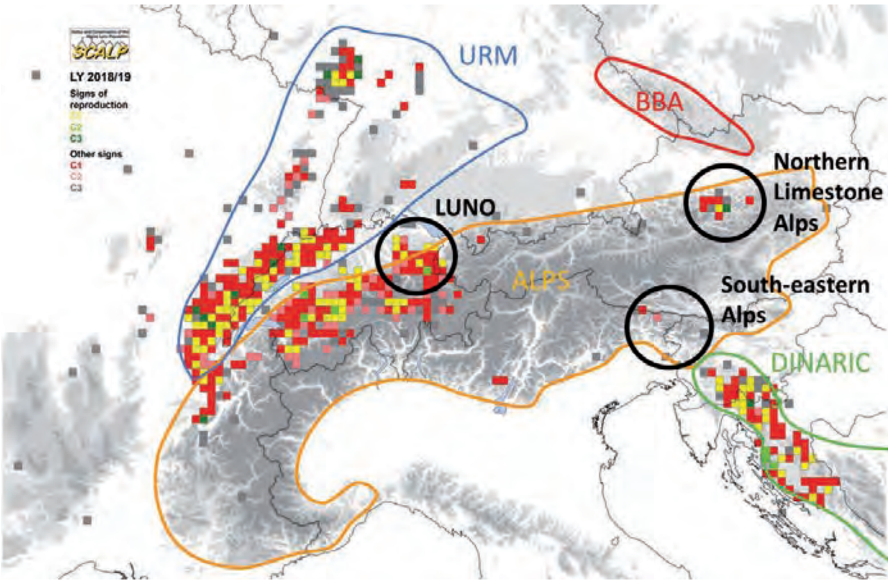

Fig. 1. Lynx distribution in the Alps, northern Dinarics, and Upper Rhine metapopulation (URM) based on SCALP categorisation (Molinari-Jobin et al. 2012) in 2018/2019. Mountain ranges are outlined in different colours (URM = blue, Alps = orange, Dinaric range = green, Bohemian Bavarian Austrian Forest = red). The stepping-stone occurrences are indicated with black circles. For C1, C2, C3 see Molinari-Jobin et al. 2021.

LUNO stepping-stone population is about to merge with the north-western Alpine population in Central Switzerland, although no exchange of individuals has been confirmed yet by camera trapping. Interestingly, an immigrant from the Jura Mountains was confirmed. Whether it reproduced is still open.

The situation leading to the stepping-stone project in the Limestone Alps, in the area of National Park Kalkalpen (NP Kalkalpen), in Upper Austria was different (Fig. 1). In the late 1990s a male lynx of unknown origin appeared in the region. Based on the monitoring data, he remained the only lynx in the region for years and was detected from 2000 –2012. In 2007 LUKA (Luchsarbeitskreis), a committee including representatives of all interest groups, was formed with the aim to establish a lynx occurrence with regular reproduction in the area of NP Kalkalpen and to balance stakeholder interests. From 2011 to 2013 two females and one male lynx were translocated from the Swiss Jura Mountains and the north-western Alps to the NP Kalkalpen. The lynx established the typical land tenure system and in 2012 the first litter was reported (Fuxjäger 2020). The number of litters increased to two with six cubs in 2013 and three litters and four cubs in 2014. In 2013 however, the translocated male lynx disappeared, and no reproduction was observed in 2015, 2016 and 2017 (Fuxjäger 2020). Two male lynx were illegally killed in 2014 by two hunters who were later convicted. The denunciations were based on criminal law (§181 StGB) and civil law (additional compensation payments), the first of their kind in Austria. Thereupon the LUKA group decided to reintroduce two more lynx as a replacement for the proven illegal killings. In 2017 a male and female from the Jura Mountains were released. A cub from 2013 migrated to the Wilderness area Dürrenstein, approximately 50 km east of the NP Kalkalpen and was documented there in 2014 and 2015 (Fig. 2). In 2016 there was no evidence for lynx occurrence in the Dürrenstein area. But in 2017 and 2018 lynx was photographed again, however, based on picture quality individual identification was not possible. In 2018 one cub could be documented only once in the NP Kalkalpen and none in 2019, respectively, despite the confirmed presence of three males and three females in the area of NP Kalkalpen (Fuxjäger 2020). So far this stepping-stone population remained small and isolated. Due to the small genetic source, inbreeding is a constant threat to the population. The fact, that there is no population exchange with other lynx populations, neither the Alpine nor the Bohemian Bavarian Austrian (BBA) population, aggravates this effect and prevents the contemplated stepping-stone function of the northern Limestone Alps.

An Urgent Lynx Conservation Action (ULyCA) was initiated in 2012 when the decrease

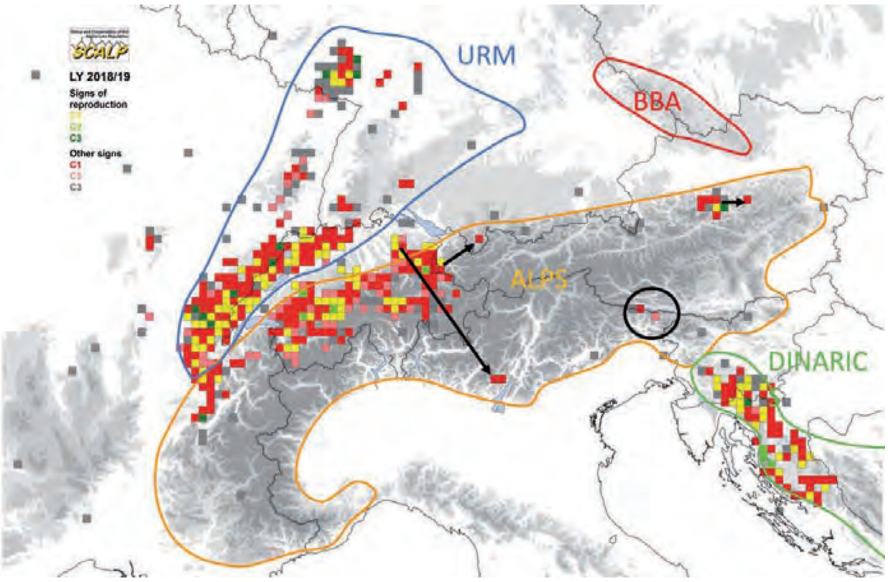

Fig. 2. Isolated lynx occurrences in the Alps are the result of dispersal from the stepping-stone populations (black arrows).Mountain ranges are outlined in different colours (URM = blue, Alps = orange, Dinaric range = green, Bohemian Bavarian Austrian Forest = red).

of lynx in the south-eastern Alps became evident (Molinari-Jobin et al. 2018). The aim was to prevent the extinction of the local occurrence by reinforcing it with 3 individuals. This action should buy time to prepare a larger project to save the local lynx population (see below). In 2014, a male and a female lynx from the Jura Mountains were translocated to the Julian Alps of Italy. Different to all other translocations, a soft-release protocol was applied in the ULyCA project (Fig. 3). One month after the release, both lynx had crossed the highway and moved into the Carnic Alps, where the female gave birth to two kittens. The male moved on, crossed the Alps northwards to settle at the Austrian-German border where he was illegally killed in September 2017, 140 km straight-line from the release site. The female stayed in the Carnic Alps where she however had no contact to other lynx. The project has been prepared in full respect of national and international guidelines (AA.VV. 2007, IUCN 1998, 2013), e.g. the favourable opinion of hunters and politics was obtained. Nevertheless, after a replacement at the top of the local hunting association and the regional political panel, an opposition started leading to blocking the release of the third lynx and the whole project. At present, five years later, the political situation has changed again and the ULyCA project might be resumed.

In 2016 the larger project, LIFE Lynx, was approved for funding and started in 2017. The aim of LIFE Lynx is to prevent the extinction of lynx in the Dinaric Mountains and south-eastern Alps (Fležar et al. 2021). The plan includes the integration of 9 new lynx into the Dinaric population, as well as to create a stepping-stone population in the Alps. Five lynx were released in the Slovenian Alps in April 2021. Until present, they all stayed in the surrounding of the release sites, but it is too early to know where they will establish their territory.

Conclusion

Twenty years after the creation of the first stepping-stone population it is still too early to draw final conclusions. But the present situation is promising (Table 1). The LUNO population is slowly expanding to western Austria and south-eastern Switzerland, and most importantly it is close enough to other lynx populations, e.g. the north-western Alps, Jura Mts., potentially to Upper Rhine Metapopulation (Swabian Alb-Black Forest, Herdtfelder et al. 2021) to allow the exchange of individuals. On the contrary, in the south-eastern Alpine population neither reproduction nor immigration was reported recently. The experience from the ULyCA project has shown that random and unpredictable socio-political events, even at local level, can seriously compromise the success of a project in spite of serious planning and implementation. The reinforcement in the frame of the LIFE Lynx project was urgently needed. Five lynx were released 60–70 km away from the northern edge of the Dinaric population (Fležar et al. 2021), close enough for dispersing lynx to immigrate into the stepping-stone occurrence (Čop & Frkovič 1998).

In contrast, the situation of the Limestone Alps stepping-stone population remains critical. With the integration of two additional lynx in 2017, the stepping-stone nucleus was saved in the short-term from extinction. However, future active management will be necessary, as small number of individuals, inbreeding, stochastic events and illegal killings may threaten the population. Compared to the other two stepping-stone populations, the lynx of the Limestone Alps lack a close-by neighbouring population that could provide immigrants in the near future. Although the BBA lynx population (Wölfl et al. 2021) is only 80 km away, they are separated by the Danube valley with its cultivated landscape. The distance to the stepping-stone occurrences in the south-eastern Alps is 140 km and to east-

Table 1. Comparison of stepping-stone projects. Number of animals released in brackets are yet to be released.

Project	Area of releases	Timeframe	Nr of animals released [m/f]	Estimated number of individuals 2018
LUNO	North-eastern Switzerland	2001-2008	5/7	25
NP Kalkalpen	Upper Austria	2011-2017	2/3	7
ULyCA	South-eastern Alps (I)	2014	1/1+(1+)	} 5-7
LIFE Lynx	South-eastern Alps (SLO)	2021	2/3	

ern Switzerland 350 km, respectively. Therefore, if the lynx nucleus of the Limestone Alps is to survive, other reinforcements will be necessary. Otherwise the lynx there will face the same destiny as the Austrian brown bear population that went extinct after a reintroduction project in the 1980s (Kruckenhauser et al. 2009). However, with the creation of another stepping-stone in-between the south-eastern Alps and the Limestone Alps, the survival perspective of the Limestone lynx would likely considerably improve. A population viability assessment (PVA) combined with habitat modelling should be performed to guide the stepping-stone approach regarding release locations and number of individuals. Assuming that large-scale reintroduction projects within the Alps or anywhere else in western or Central Europe will be difficult to implement in the future, the stepping-stone approach to connect small and isolated populations seems an adequate strategy. The here presented experience indicate that the vicinity to other lynx and the number of animals released in the frame of an adaptive release strategy (monitoring and further releases if needed) might be the crucial elements defining the success of these small case reintroductions.

Fig. 3. Lynx release in the south-eastern Alps in 2014. Prior to release, the two translocated lynx spent 17 days in a soft release enclosure (visible in the background) to avoid homing (Photo R. Pontarini).

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SCALP: Monitoring the Eurasian lynx in the Alps and beyond

The project Status and Conservation of the Alpine Lynx Population SCALP is an ongoing programme aiming to coordinate the Eurasian lynx *Lynx lynx* monitoring, conservation and management activities in the Alps, but the monitoring approach has recently been expanded to the neighbouring Dinaric and Jura Mountains. The long-term goal of the SCALP is to help the still small and isolated reintroduced populations to expand and to recover in co-existence with people. The process is advanced and supervised by the SCALP Expert Group, which also prepares yearly distribution maps.

Since the foundation of the SCALP Group in the early 1990s, we have gained considerable experience with monitoring of this elusive species. In the context of species distributions, false-positive observations arise when a species is recorded erroneously at a place where it does not occur, most often because another species is mistaken for the focus species. To identify the potential cases of false-positive observations, we developed the so-called "SCALP Criteria" where each sign of lynx presence is categorised based on the possibility to verify and confirm the reported observation. With lynx, the following categories are used (Molinari-Jobin et al. 2012):

C1 – Confirmed hard facts, verified and undisputable records of lynx presence with material evidence, such as (1) dead lynx, (2) captured lynx, (3) georeferenced lynx photos, and (4) samples (e.g. excrements, hair) attributed to lynx by means of a scientifically reliable analysis (e.g. genetics).

C2 – Records confirmed by a lynx expert (i.e. trained member of the network) such as (1) livestock or (2) wild prey killed by a lynx, (3) lynx tracks or other assessable signs of presence.

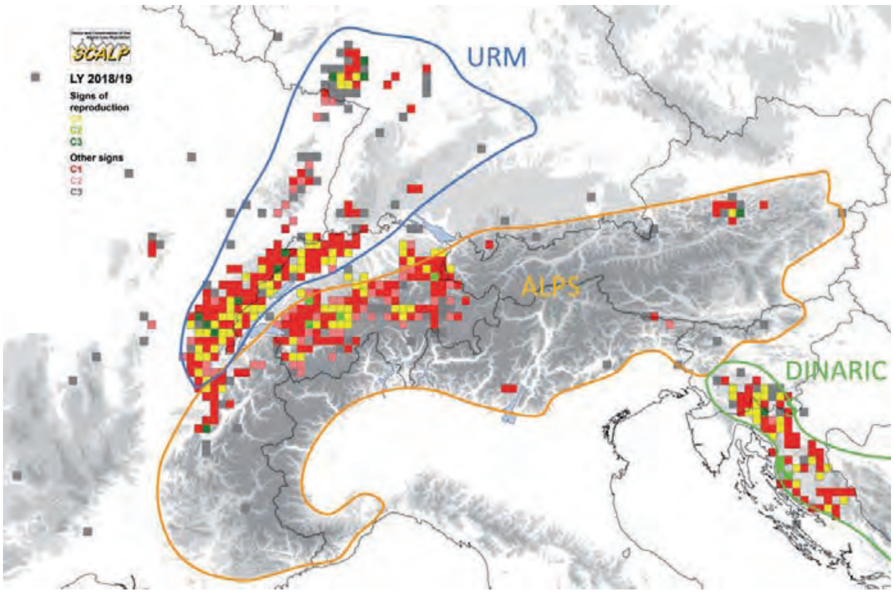

Fig. 1. Lynx distribution in 2018 in the Upper Rhine Metapopulation (blue), the Alps (orange) and the Dinaric Mountains (green) based on the SCALP criteria where hard data (C1) is separated from confirmed data (C2) and data not verified (C3). Presence signs of reproduction are also distinguished. The squares represent 10x10 km cells of the European Terrestrial Reference System 1989.

C3 – Unconfirmed records, chance findings (kills, tracks and other field signs too old or badly documented, where however the description conforms to a lynx sign) and all observations such as direct sightings and calls, which by their nature cannot be verified.

We used site-occupancy modelling to estimate lynx distribution and showed that the inferred distribution is highly sensitive to presence category, where C3 data had a much wider distribution than C1 and C2 data (Molinari-Jobin et al. 2012). We recommend rigorous discrimination between fully reliable and un- or only partly reliable data in monitoring datasets. However, despite containing potentially false-positive observations, "soft" data (C3) are not discarded: They increase the precision of parameter estimates in dynamic occupancy models (Louvrier et al. 2018) and are valuable to indicate expansion or regions where the monitoring needs to be improved.

Although this type of categorisation needs to be adapted to the focal species, a distinction between "hard" and "soft" data can help to raise awareness about the fact that false species identification may exist in the monitoring dataset, and thus facilitate the adjustment of the survey and hence the population status assessment. We have further improved the lynx distribution maps by differentiating between 10x10-km presence cells with and without reproduction classified according to the SCALP criteria (Fig. 1).

It is not only important to consider false positive data. Lynx detection probability varies in space and time. Therefore, we also have explored methods considering imperfect detection when producing distribution maps (Molinari-Jobin et al. 2018). Site occupancy models jointly estimate occurrence and detection probability (MacKenzie et al. 2002, 2003) and are able to correct for improvements in monitoring efficiency. In the Alps, improvements in monitoring over the past 25 years were achieved both through better training and advanced experience of monitoring network members as well as the increased and nowadays widespread use of camera traps. Lynx distribution and detection probability varied by year, country, forest cover, elevation and distance to the nearest lynx release site (Molinari-Jobin et al. 2018). Occupancy of neighbouring cells had a strong positive effect on colonisation and persistence rates. Our analyses demonstrated the importance of accounting for imperfect detection: The raw data underestimated the lynx range by 55% on average, depending on country and winter. We recommend calibrating the naive distribution at least once in a generation time using site occupancy models.

We have considerably advanced our knowledge of the species' distribution, but have only just started to address the "how many" question. Although at local scale spatial capture-recapture modelling gives excellent results (Zimmermann et al. 2013, Zimmermann & Foresti 2016), the extrapolation to the large scale, e.g. population level, remains a challenge. Similar to distributional data, it is desirable to standardise also the interpretation of abundance estimates, which presently range from expert guestimates, minimum counts through camera trapping to robust estimates based on capture-recapture methods, which themselves require standardisations. At present, we are in the process of developing SCALP criteria for abundance estimates.

Fig. 2. Scalp expert group members regularly meet to discuss progress and challenges, e.g. members from Slovenia, Italy, Austria, Germany, Switzerland, France and Fürstentum Liechtenstein met in Berchtesgaden, Germany, in September 2018.

Since the start of the SCALP cooperation in the early 1990s, the experts (Fig. 2) have emphasised that connecting the isolated lynx populations is vital for lynx conservation. The basis for a recovery strategy is the Pan-Alpine Conservation Strategy for lynx (PACS; Molinari-Jobin et al. 2003), produced by the SCALP expert group and adopted by the Standing Committee of the Council of Europe's Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) in 2001. Over the past 20 years, the Alpine lynx range has expanded at an average rate of 4% per year, which was mainly the result of translocation projects (Molinari-Jobin et al. 2018): 12 lynx were translocated from the north-western Swiss Alps and Jura Mountains to north-eastern Switzerland from 2001–2008, five lynx from the north-western Swiss Alps and Jura Mountains to Upper Austria between 2011–2017, two lynx from the Jura Mountains to north-eastern Italy in 2014 and another five lynx were captured in the Carpathians and relased in the Julian Alps of Slovenia in 2021. Lynx have so far recolonised less than 20% of the Alps (Fig. 1). The translocation projects all base on the "stepping-stone idea" (Molinari et al. 2021) that has been adapted to lynx conservation in the frame of the SCALP project.

Assessments published since the year 2000 largely agree on main threats to the lynx populations in the Alps (Molinari-Jobin et al. 2003, Molinari-Jobin et al. 2010, Schnidrig et al. 2016) and in Europe in general (Breitenmoser et al. 2000, von Arx et al. 2004, Council of Europe 2012, Kaczensky et al. 2013, Boitani et al. 2015). They consist mainly of illegal persecution, accidental mortality (vehicle collisions), habitat deterioration due to infrastructure development. Low acceptance due to conflicts with hunters, combined with the intrinsic limited dispersal capability of the species add to the slow expansion of the Alpine lynx population. The more recent assessments also identified inbreeding as an important threat for some of the lynx populations (Schnidrig et al. 2016). Additionally, Boitani et al. (2015) list poor management structures as a factor impeding lynx conservation in Europe. Based on these threat assessments, as well as social and political considerations, management scenarios for advancing the recovery of the Alpine lynx population were developed on behalf of the Alpine Convention (Schnidrig et al. 2016).

Although the Alpine lynx population is still far from being (genetically) viable, it is the only mountain range in Western and Central Europe that could host an isolated viable population considering its potential extent. The Alps are hence a future stronghold for the species and also crucial with regard to connecting with neighbouring populations, e.g. the Dinaric, Bohemian-Bavarian-Austrian, Black Forest and Jura Mountains populations (von Arx et al. 2021). The overall goal is to build up a large Central European metapopulation (Bonn Lynx Expert Group 2021). The connection between the eastern and western Alps is decisive, but will in due time only be achieved through active management, as the extant lynx sub-populations are spreading very slowly. Moreover, the Alpine population has a very low genetic variability as a consequence of a very small founder group, and needs genetic management (Breitenmoser-Würsten & Obexer-Ruff 2003; Reiners et al. 2021). Therefore, further translocations and reinforcements will be necessary, such as current efforts taking place in Slovenia and Croatia as part of the LIFE Lynx project (Fležar et al. 2021). To foster the population spread and assure the demographic and genetic rehabilitation, a coordinated approach with a step-wise improvement in all small subpopulations is recommended (Fig. 3). In the frame of the SCALP project, we have developed widely recognised best practice approaches for monitoring and management that were applied also for several other conservation projects in the Alps and beyond.

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Fig. 3. Translocations are an efficient tool for improving the outlook of small populations (Photo R. Pontarini).

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Favourable conservation status and population level management – the Bohemian-Bavarian-Austrian lynx population as a case study

For strictly protected species, the European Union's Habitats Directive obliges member states to keep or head for a favourable conservation status FCS. Within the "3Lynx-Project", 11 partners from 5 countries developed a population level based conservation strategy. To operationalize the FCS-concept, we used the criterion D (population size) of the IUCN Red List category Near Threatened and translated it into specific minimum population size. For the Bohemian-Bavarian-Austrian BBA lynx *Lynx lynx* population we came up with 250 mature animals, being implied that connectivity to other lynx populations is simultaneously assured. The key monitoring unit is defined as the number of reproducing females. To reach FCS, a number of 165 verified females with kittens within the BBA-population is targeted.

The European Union's Habitats Directive obliges member states to keep or head for a favourable conservation status (FCS) for strictly protected species (European Economic Community 1992). The Eurasian lynx as listed in Annex II and IV of the Habitat Directive is a species with high spatial demands averaging 1 adult animal per 100 km² only (Breitenmoser & Breitenmoser-Würsten 2008). The big challenge is how to integrate a population large enough for FCS into the human dominated, cultural landscape of Central Europe.

Within the so called "3Lynx Project", eleven partners from five countries (Czech Republic, Germany, Austria, Italy and Slovenia) worked on harmonisation of lynx monitoring and exchanged regional and national experience on conservation efforts with respect to population level management (e.g. Wölfl et al. 2021). The main emphasis lay on the development of a conservation strategy for the Bohemian-Bavarian-Austrian BBA lynx population (Fig. 1). There, lynx live along the mountain ranges stretching along the border area between Czech Republic, Germany and Austria (Fig. 2).

Fig. 1. Participants of a workshop of the 3Lynx project gathering for the development of a conservation strategy for the BBA lynx population (Photo Czech Ministry of Environment).

Lynx were extirpated in this area in the 19th century – last records stem from early beginnings of the 20th century (Bufka & Červený 1996). In the 1980s a total of 17 lynx of Carpathian origin were reintroduced in the area of the later founded Šumava National Park (Bufka & Červený 1996, Volfová & Toman 2018). With-in the next decades this nucleus developed into the currently existing BBA lynx population (e.g. Wölfl et al. 2001,Wölfl et al. 2021).Although suitable habitat is largely avail-able, the BBA lynx population is – with 107 independent animals and 32 family groups (Mináriková et al. 2019) – still relatively small and isolated. Moreover, parts of the area are quite fragmented. These factors contribute to the risk of low genetic variability leading to extinction again.

The "Guidelines for population level management plans for large carnivores in Europe" (Linnell et al. 2008) have been recommended by the EU commission to give practical advice for defining and reaching FCS on population level for medium sized mammals. This means a transboundary conservation approach in terms of numbers and space for most of Europe's large carnivore's occurrences.

Within the 3Lynx-Project the overall vision for the BBA lynx population is therefore stated as follows: the continuous development of the BBA lynx population towards a long-term survival in a favourable conservation status which implies 1) lynx spread all over suitable habitat within the BBA area, 2) lynx reach sufficient numbers within the BBA area, 3) BBA lynx population is connected with other lynx sub-populations to build up a functioning metapopulation, and 4) lynx is accepted by humans as an integral part of the Central Europe ecosystem.

Concerning habitat within and around the BBA area, conservation steps are 1a) to secure and improve lynx habitat on a small habitat specific scale (e.g. key reproductive sites and prey base); 1b) to secure and improve connectivity within BBA area (e.g. permeability of roads or highways, mountain valleys which are very often continuously built up by settlements with less and less possibilities for animal movement); 1c) secure and improve connectivity to other lynx populations (Carpathian, Alpine or Harz mountains). For reaching connectivity to the Carpathian population, the so-called "CELTIC" concept (Conservation of the Eurasian Lynx – Management and International Cooperation; Wölfl et al. 2001) could serve as a guideline.

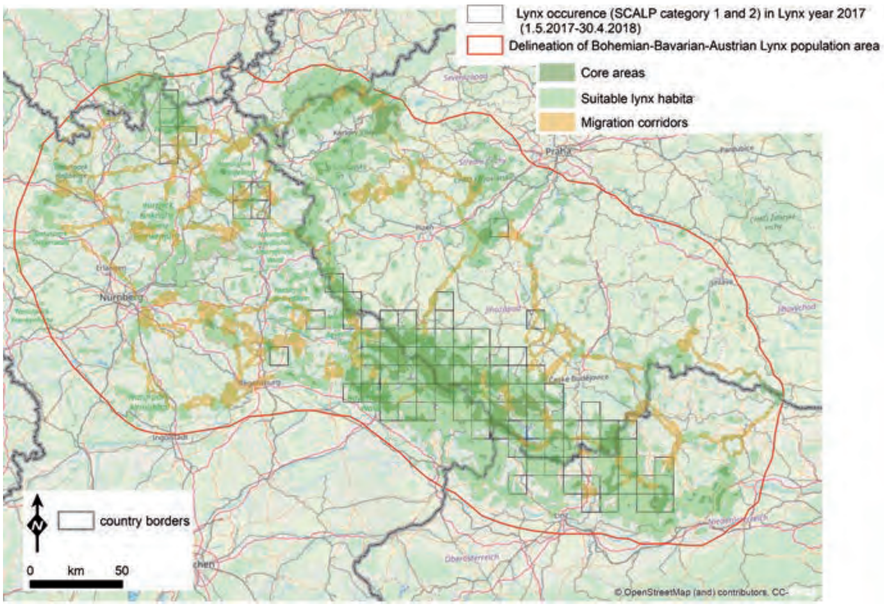

Fig. 2. Delineation, suitable habitat and current distribution of the Bohemian-Bavarian-Austrian (BBA) lynx population (Lynx Year 2017: 01.05.17–30.04.2018; Mináriková et al. 2019).

An important issue for "reaching sufficient numbers" is the translation of the legal obligation for FCS into practical goals. One pragmatic approach is to refer to the criterion D (population size) of the IUCN Red List category Near Threatened and use the translation into numbers given in the "Guidelines for population level management plans of Large Carnivores in Europe", being for an isolated lynx population 1,000 mature animals (category Near Threatened), or 250 mature animals for an occurrence being connected to other populations (category Vulnerable).

For lynx, 1,000 mature animals would mean a spatial demand of approximately 100,000 km². The BBA area is not large enough to correspond to these numbers, so the logical consequence is to pursue two parallel approaches: hosting at least 250 mature lynx and securing genetic exchange between neighbouring sub-populations.

As the 250 mature animals are stated in the above mentioned guidelines as the absolute minimum numbers we propose to count only actually reproducing animals to be well above the critical bottom line. Taking lynx social organisation into account (on average one male covers the home ranges of two females – see Fig. 3) to reach 250 animals taking part in reproduction we therefore propose to strive for at least 165 reproducing females and 85 males within the BBA population.

The key monitoring unit should be the „lynx family group", which means a female lynx with documented kitten(s) – synonymous to "reproducing female or lynx family". Taking the spatial ratio of 2 females per 1 male into account we then head for at least 165 lynx families to reach FCS within the BBA population. These required numbers are to be distributed between the three EU member states Czech Republic, Germany and Austria, respectively, according to available habitat.

To further assess, refine and evaluate the given argumentation we will conduct additional analyses (population viability analysis, occupancy and habitat model) after the 3Lynx project. To support these analyses with data we will focus on improving our data base on population structure and dynamics and on a comprehensive evaluation of the inbreeding coefficient.

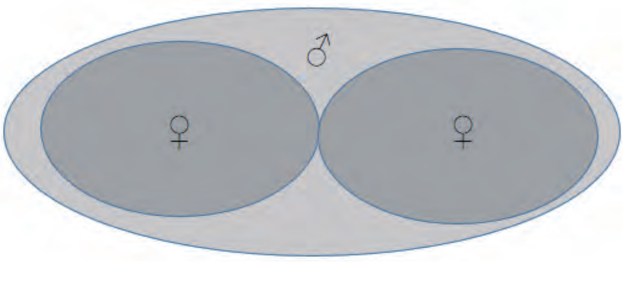

Fig. 3. Lynx social organisation – on average one adult male covers the territories of two adult females.

Regarding the acceptance of lynx as an integral part of the transboundary ecosystem a communication concept has been developed within the 3Lynx-Project which will be part of the BBA conservation strategy as well.

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Transboundary cooperation in lynx conservation under the auspice of the Upper Rhine Conference

The reintroduction of lynx *Lynx lynx* to the Palatinate Forest with adjacent suitable habitats in France, Switzerland and Germany spurred the interest to augment the international cooperation to exchange information, develop harmonized approaches and to establish supporting organisational structures. Thus, the Expert Committee Lynx has been established under the auspices of the Upper Rhine Conference and functions as an administrative umbrella to the protruding lynx habitats.

The Upper Rhine is framed by the secondary mountain ranges of the Black Forest, the Jura, the Southern Vosges and the Northern Vosges-Palatinate Forest (Fig. 1). The lynx was reintroduced to the Swiss Jura in the 1970s and to the French Vosges in the 1980s. In the Black Forest, single male lynx are regularly observed. The Palatinate Forest population is currently being reintroduced (Drouet-Hoguet et al. 2021; Germain & Schwoerer 2021; Herdtfelder et al. 2021; Idelberger et al. 2021).

A demographically and genetically viable lynx population requires a large extension, which could be achieved by combining the subpopulations into a "metapopulation". Together, the mountain ranges bordering the Upper Rhine, the Black Forest, the Jura, the Southern Vosges and the Northern Vosges-Palatinate Forest, form a semi-natural living space of around 36,000 km² and could accommodate a viable "Upper Rhine metapopulation" (URM) of lynx. This URM is furthermore connected to the Alps and the Swabian Alb, and, eventually, to secondary mountain ranges further north. The secondary mountain ranges, forested in large areas, provide favourable habitats for the lynx (Schadt 2002; Zimmermann & Breitenmoser 2007), but the populations are still small, vulnerable and separate. The only significant population consists of about 150 independent lynx in the French-Swiss Jura, while only a few individuals live in the Vosges-Palatinate Forest region and male lynx from the Swiss Jura occasionally migrate to the Black Forest (Drouet-Hoguet et al. 2021; Herdtfelder et al. 2021; von Arx et al. 2021). Single lynx are observed in the Southern Vosges (Germain et al. 2021).

The reasons for the slow expansion are the biology of the lynx (Zimmermann et al. 2007), especially the limited willingness of females crossing the fragmented landscape, but also a high anthropogenic mortality, not at least due to the fragmentation of habitats and illegal killings due to the low acceptance of the lynx among parts of the local population. A further threat is genetic impoverishment through inbreeding, as long as the individual populations remain isolated. A functional Upper Rhine metapopulation requires the natural or assisted dispersal of lynx between these healthy subpopulations and the colonisation of further existing suitable habitats especially by females. Based on documented migrations, we hypothesise that natural migration would be sufficient to maintain the genetic viability of the population if once vital subpopulations exist in all ranges. So far, 13 male lynx migrated to the Black Forest and adjacent secondary mountain ranges. For seven individuals, the Swiss origin has been documented (Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg 2019; Herdtfelder, pers. comm.). Another male migrated from the French Jura to the Southern Vosges in 2015 (Hurstel & Laurent 2016). From Palatinate Forest to the Southern Vosges mountains two males migrated, with several individuals more exploring the Northern Vosges mountains in excursions or as part of their territory. One male crossed the river Rhine from Ludwigshafen to Mannheim (Idelberger et al. 2021). Rivers of this size are usually considered as major barriers (Schadt 2002).

On the institutional side the necessary cross-border cooperation has been initiated at the Franco-German-Swiss Conference of the Upper Rhine (Upper Rhine Conference). The Upper Rhine Conference provides the institutional framework for cross-border cooperation in the region. It is the successor organisation to the two regional commissions (bipartite regional commission for the northern and tripartite regional commission for the southern Upper Rhine region) which de-

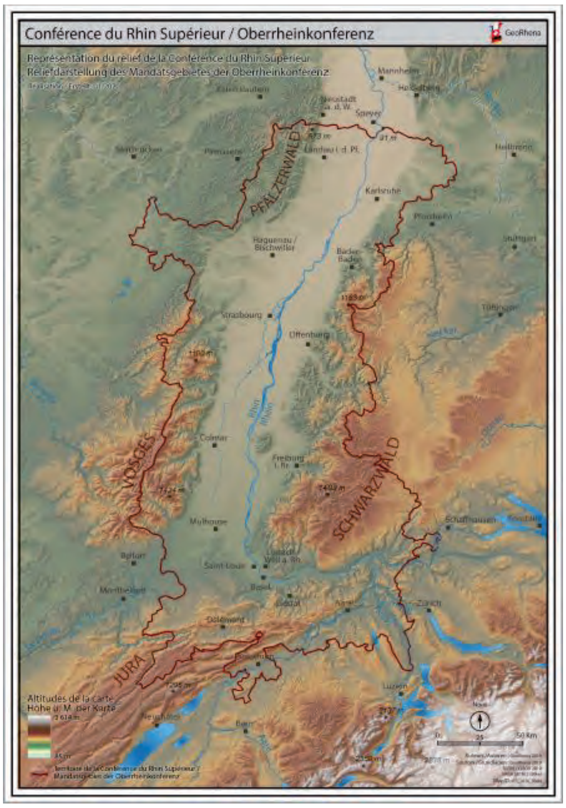

Fig. 1. The mandated territory of the Upper Rhine Conference (red outline) and the included mountain ranges of Jura and Vosges Mountains, Black Forest and Palatinate Forest (Oberrheinkonferenz 2012).

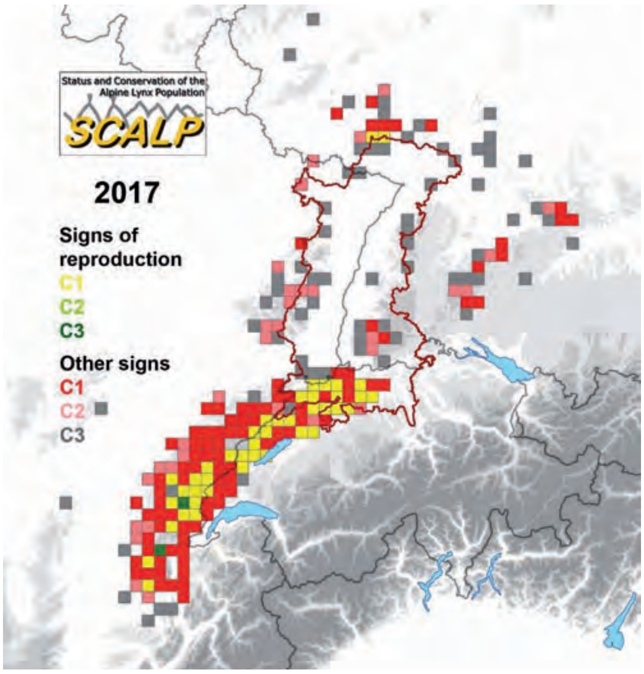

Fig. 2. As a result of the Expert Committee Lynx, a joint distribution map according to the SCALP criteria has been created for the Upper Rhine area (Molinari-Jobin, unpubl.). The red demarcation shows the mandated territory of the Upper Rhine Conference

rived from the 1975 Upper Rhine agreement between Germany, France and Switzerland and which were established to work under the auspices of the Franco-German-Swiss Intergovernmental Commission (The Upper Rhine Conference: https://www.oberrheinkonferenz.org/de/services/english.html, accessed on 19.12.2019).

The governments of France, Switzerland and Germany have welcomed the establishment of the Expert Committee Lynx (https://www.oberrheinkonferenz.org/de/umwelt/arbeitsgruppe.html, accessed on 17.01.2020) at the Intergovernmental Commission meeting in Berlin on 23. October 2015. The Expert Committee constituted on 27.10.2016 to work on demographic and genetic monitoring, interconnection, acceptance and management. The effectiveness of the institutional platform to address current challenges in the conservation of lynx will depend on the ability and willingness of the participants to cooperate, on available resources and on the socio-political measures proposed in each region.

The mandated territory of the Upper Rhine Conference embraces sections of three extant or potential lynx populations, namely the Jura, the Vosges-Palatinate Forest and the Black Forest populations (Fig.1). As already mentioned, this URM is connected to adjacent secondary mountain ranges.

The Expert Committee Lynx at the Upper Rhine Conference elaborated in a first step methods and instruments on demographic and genetic monitoring and agreed to consolidate national data to allow for an overarching presentation of the URM (Fig. 2) using the SCALP criteria for the evaluation and transformation of national data (Molinari-Jobin et al. 2021).

In order to establish and maintain an Upper Rhine metapopulation, (1) a demographic-genetic, spatially explicit model for a potential metapopulation should be developed, (2) shared and standardised monitoring, conservation and management measures in accordance with the „Guidelines for Population Level Management Plans for Large Carnivores"(Linnell et al. 2008) should be developed and implemented, and (3) competent authorities and interest groups should be consulted and informed, as well as the public awareness of a common, large-scale, transboundary Upper Rhine habitat should be promoted. The necessary cross-border cooperation has been initiated with the Expert Committee Lynx at the Upper Rhine Conference and should be expanded in the future.

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Effects of fragmentation and connectivity of lynx habitats on population genetics in continental Europe

Following the reintroduction and natural expansion of various Eurasian lynx *Lynx lynx* populations, new challenges are being faced. The current lack of genetic exchange between small populations due to restricted dispersal caused by human activities (i.e. habitat fragmentation, persecution, vehicle collisions) puts them at risk of stochastic demographic events, genetic drift and inbreeding. Low genetic diversity has been reported for most reintroduced populations and evidence of ill-effects due to genetic impoverishment have been shown in two reintroduced lynx populations. We present the pertinent points discussed on the topic of fragmentation and connectivity of lynx habitat, with a special focus on the discussions surrounding genetics and the requirements for long-term management of a potential "Central European metapopulation". The potential metapopulation management must be based on a good knowledge base through genetic and demographic monitoring and targeted conservation research designed to deliver prognoses required by managers. The contemporary development of a spatially explicit individual-based demogenetic simulation model has the potential to confront the future metapopulation management questions.

Decades after their local extinction, large predators such as Eurasian lynx have been able to resettle in Central Europe (Chapron et al. 2014). This was possible due to support from the general public, legal protection and reintroductions. Despite these developments, the return of Eurasian lynx does not continue unhindered. Historic preconceptions about large predators and conflicts between stakeholders mean that maintained effort is necessary to protect their survival (e.g. Lüchtrath & Schraml 2015, Červený et al. 2019). The anthropogenic influence on Central European landscapes puts populations of lynx under strain. Although there is enough habitat for lynx populations to expand, the low landscape connectivity between patches means lynx are less able to disperse (Kramer-Schadt et al. 2005). Many lynx mortality events in Central Europe are due to poaching, or traffic collisions (Schmidt-Posthaus et al. 2002, Sindičić et al. 2016, Heurich et al 2018). These factors have contributed to a stagnation of lynx populations, despite successful reproduction occurring regularly. The small size of lynx populations increases their demographic risk, namely because small and poorly connected animal populations face a higher risk of dying out due to random events (Sanderson et al. 2014). Besides demographics, a lack of genetic diversity can lead to several problems. In small populations of animals, the probability of genetic diversity being lost is higher due to genetic drift and inbreeding (Keller et al. 2012). This can have negative effects on species health, at individual and population levels, and ultimately survival (Keller & Waller 2002). Considering lynx, genetic problems have already been implicated as the likely causes of congenital heart defects found in Switzerland (Ryser-Degiorgis et al. 2004), and the collapse of the Dinaric population (Sindičić et al. 2013). The longer small populations of animals remain separated, the higher the risk of genetic side effects. A loss of genetic diversity has already been reported in many Central European lynx populations (e.g. Sindičić et al. 2013, Bull et al. 2016). The decline of reintroduced lynx populations' genetic diversity in Central Europe motivates a discussion about the potential management actions required to maintain these populations over the long-term. The ultimate goal of such thoughts is the creation of a "Central European metapopulation", which should include all reintroduced populations with connections to autochthonous populations (Fig. 1). Here we outline the discussion and indicate where a spatially explicit individual-based demogenetic simulation model could help support the discussion by delivering prognoses under the diverse scenarios discussed.

Discussion for long-term management

Habitat fragmentation and anthropogenic mortality

The fragmentation in Central Europe cannot be assumed to improve in the next decades (Tillman 2005). Although construction of new roads in EU member states requires planning of 'green bridges', the existing infrastructure already presents an apparently large barrier to lynx dispersal (Kramer-Schadt et al. 2004). This is epitomised by the high road mortality figures in some populations. In addition, traffic density is projected to increase (Petersen et al. 2009). For many lynx populations there is no shortage of habitat for residence or dispersal and prey numbers are sufficient (Apollonio et al. 2010), unfortunately human factors, such as poaching (Lüchtrath & Schraml 2015) and road mortality (Kramer-Schadt et al. 2004, Andrén et al. 2006), prevent lynx from expanding their range. In Central Europe, poaching remains a significant source of mortality in various lynx populations (Heurich et al. 2018, Arlettaz et al. 2021). Human acceptance of large carnivores might change with time, but few poachers can do a lot of damage in small populations. It is possible that the existing connectivity is enough concerning demographics, however the low rate of dispersal suggests that this might be too slow regarding genetics. Therefore, discussion during the conference was based on the worst-case assumption that connectivity is not adequate for lynx to naturally build a metapopulation and will at the very least require some support.

Monitoring and research

Planning management actions requires a good knowledge base. Currently, the empirical information on the reintroduced Central European lynx populations is good. This includes, in most cases, rigorous monitoring using camera traps and genetics. The Carpathian "source" population (mainly Slovakia, Romania, and Ukraine) is a lesser-known entity. In the last years, systematic monitoring projects employing camera traps and snow tracking have begun gathering information in some regions (Kubala et al. 2019). However, further systematic camera trapping to illuminate the unknown regions is still needed. Furthermore, a broad genetic census of the Carpathian lynx population is lacking. These would represent important building blocks upon which to base future management discussions. Ide-

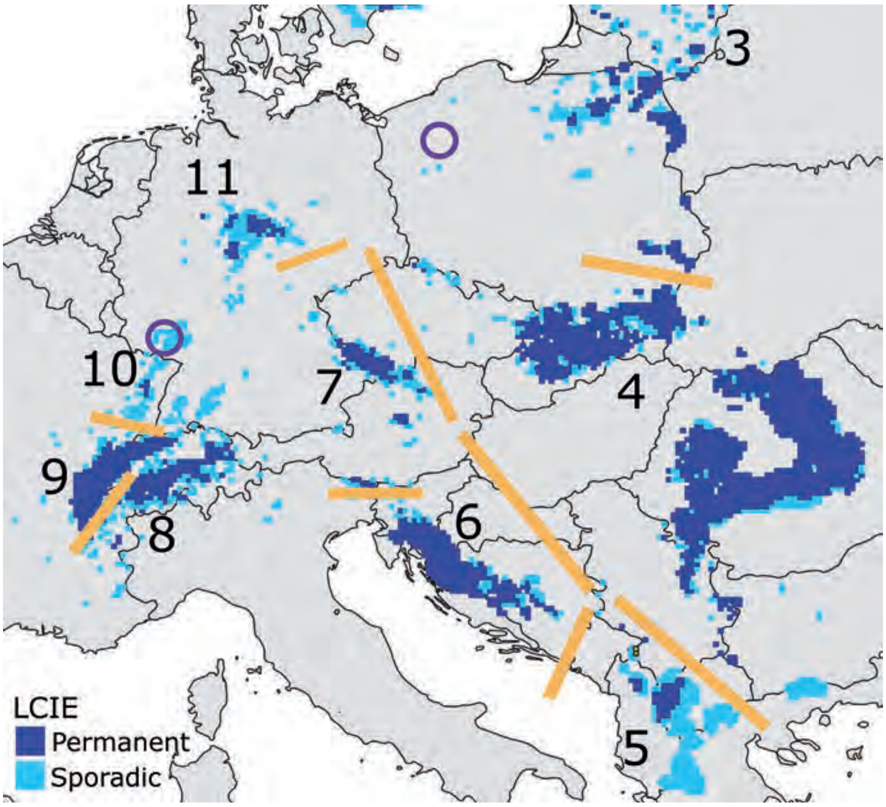

Fig. 1. Distribution map of Eurasian lynx in 2016 from Large Carnivore Initiative for Europe assessment (LCIE, Kaczensky et al. 2021) and delineation (orange lines, Chapron et al. 2014) of reintroduced (6 – Dinaric, 7 – Bohemian-Bavarian-Austrian, 8 –Alpine, 9 – Jura, 10 – Vosges-Palatinate, 11 – Harz Mountains) and autochthonous (3 – Baltic, 4 – Carpathian, 5 – Balkan) populations in Central Europe, with the approximate locations (purple circles) of reintroduction projects in the Palatinate Forest and north-western Poland.

ally, all lynx populations would be subject of continuous demogenetic monitoring with coherent methods. This means applying standards for camera trapping and analysing similar gene loci panels to enable cross-comparisons.

Conservation research should support management not only by providing high quality information from demogenetic monitoring, but also by providing prognoses, as well as recommendations, such as targets (e.g. for genetic status) and actions to achieve them. One approach under development is an individual-based demogenetic model which can be used to simulate spatially explicit management scenarios (Premier et al. 2020). This is based on an existing lynx model (Kramer-Schadt et al. 2005), which has been expanded with neutral genetic markers (i.e. microsatellites). The goal of this work is to simulate metapopulation management scenarios and understand their effects on genetic diversity and exchange, both within and between the individual populations in order to support management decisions. The demogenetic model is flexible and will be capable of simulating demographic and genetic development under diverse conditions. In brief, it can simulate any chosen genetic starting conditions since the sex, genotype and location of all initial lynx are defined a priori. Additional lynx with any genotype can be released at any given time to simulate reinforcement or translocation. In addition, it can simulate spatially explicit and temporally defined mortality scenarios, e.g. with less poaching. Landscape connectivity can be considered using a spatially explicit map of habitat preference, currently with the levels: barrier, matrix, dispersal and breeding habitats. Furthermore, a road risk map is used to consider the additional mortality risk imposed on dispersers crossing the landscape. A first step with simulations at the Central European scale will be to investigate the potential of natural dispersal to connect different small populations and thereby suggest priority populations for management actions. The ultimate plan is to use this demogenetic model to determine the required rates, origins and destinations of translocation or reinforcement within a Central European metapopulation in order to reach certain genetic goals.

Metapopulation management potential

If natural dispersal will not be sufficient, or sufficiently fast, to protect given reintroduced populations from potentially negative effects of genetic drift and inbreeding, there are essentially three potential management options:

i) population reinforcement from source populations. Population reinforcement from source populations such as the Carpathian is one option. In recent years there have been two projects translocating individuals from the Slovakian and Romanian Carpathians for reintroduction (Palatinate Forest, Germany: 8 individuals, 2016–2020) and reinforcement (Southeast Alps and Dinaric Mountains, Croatia/Slovenia: 13 individuals, from 2019–ongoing). It has long been assumed that the Carpathian population is large and stable enough to be a source population. There is however a general need to improve the basic knowledge on the population status and biology as well as on human attitudes in this region for further wild lynx translocations. For these reasons, the most suitable way may be the use of orphans. Although in specific circumstances orphans might be supported in the wild (Premier et al. 2021), individuals that are otherwise unlikely to survive in the wild or would spend their whole lives in captivity might be translocated advantageously in metapopulation management. Besides autochthonous populations, reintroduced populations could be used as a source, for example along with 10 Slovakian lynx an additional 10 lynx were caught in Switzerland for the recent Palatinate Forest reintroduction.

ii) population management within the metapopulation. Population management within the proposed metapopulation could take a multitude of forms. At its core is the idea of translocating individuals between the isolated populations to support, or mimic, natural dispersal events. There are various aspects which must be clarified before attempting such translocations, including biological and phylogenetic factors as well as the human dimension. For example, biological factors requiring discussion include the number of individuals translocated per time unit, selection of individuals (sex/age/genetics) and origin and destination of individuals in order to maximise benefits. Regarding phylogeny, while most reintroduced populations stem from individuals from the Carpathians, zoo-born individuals have been used, too. Additionally, Europe contains three different subspecies of Eurasian lynx (Scandinavian, Carpathian, Balkan). These subspecies are not yet naturally connected, but connections may occur in the future, for example a connection of the Carpathian and Balkan lynx subspecies might become established through the reintroduced Dinaric population. How these different origins and subspecies are to be treated when planning reintroductions and reinforcements is still under discussion by the experts.

iii) support from a captive breeding program. A captive breeding program might be able to support a metapopulation as a viable source. The advantage of such a captive population is its known origins and pedigrees of individuals. The possibility to select individuals from a captive population with advantageous genotypes and release them in a target population is very attractive as it excludes the uncertain "selection" of wild captures. Some reintroductions have successfully used captive-bred animals (Harz Mountains, Germany), which suggests good potential for the use of a captive population (Mueller et al. 2020). The recent north-western Polish reintroduction has been releasing individuals (54 reported) of diverse origins, including captive-bred, the success of this project is, yet, unknown (www.rysie.org).

However, for all the options above there are many practical considerations to make, such as animal handling permissions, or quarantine. In the ideal case where translocations are part of a routine metapopulation management (e.g. translocation or release of N individuals/time/population) some administrative aspects should not have to be repeated countless times. Besides logistics, scenarios, such as i–iii and others discussed at the Bonn conference, can be the subject of future simulation studies using the above mentioned demogenetic model. Understanding the natural dispersal potential and prioritising the most at-risk populations is a key goal. In further steps, various management scenarios based on expert knowledge should be considered.

Establishing a metapopulation management

In recent years, there have been various EU funded projects, amongst others, supporting the conservation of lynx in Europe with action. These include, but are not limited to, a reintroduction project in the Palatinate Forest Germany "LIFE Luchs Pfälzerwald" (funded 2015–2021), a population reinforcement in the Dinaric Mountains of Croatia and Slovenia "Life Lynx" (funded 2017–2024), a transboundary collaboration in the Austrian-Bavarian-Bohemian region "3Lynx" (funded 2017–2020), and a reintroduction project in Poland "The Return of Lynx to north-western Poland" (funded 2016–unknown). The conservation managers and researchers involved in these initiatives are from diverse European countries, indicating a broad collaborative base keen on improving the situation of all lynx populations. This combined with financial support are prerequisite to any future European level management perspectives. Short term project-based funding might be enough for reintroduction projects or capacity building, for which the goals are short term, too. In the long-term this is unlikely to be a satisfactory solution since funding applications are time intensive and not always successful. None of the potential management measures discussed in previous sections are possible without continuous and rigorous monitoring (esp. genetic), therefore continuous funding is highly desirable.

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EUROLYNX: Collaborative science for studying Eurasian lynx movement ecology at the range of its distribution

EUROLYNX (European Lynx Information System) is an open, collaborative project based on a spatial database that stores shared Eurasian lynx *Lynx lynx* data to investigate variation in behavioural ecology along environmental gradients or population responses to specific conditions, such as habitat changes, impact of human activities, prey densities, or livestock husbandry methods. EUROLYNX aims to promote comparative theoretical and applied research into Eurasian lynx behaviour and ecology at the European scale. The open, bottom-up and cooperative structure of EUROLYNX spurs proactive engagement of partners and assures that they are involved in all stages of research. Currently, 42 groups from 19 countries have joined the initiative and nine working groups have been established to address ecological questions, to prepare research protocols and to push methodological advances forward.

In recent years, advances in research methodologies, such as genetic analysis, camera trapping, bio-logging and remote sensing, have opened new research avenues in ecology and conservation biology. In particular, the introduction of satellite-based telemetry, so called GPS telemetry, has provided the opportunity to observe wildlife behaviour in their natural habitat in an unprecedented manner at low cost (Cagnacci et al. 2010). Aside from research on migratory bird behaviour, telemetry studies have mainly been performed in local study sites by single research groups providing spatially limited insights into the ecology of the target species. Reasons for this are manifold, but the most important are probably the huge effort required to establish telemetry projects and limited possibilities for single research groups to perform studies in multiple countries. However, a continental-scale approach is needed for a better understanding of the behavioural responses to climate and ecosystem changes, management practices, and human disturbance. This was the rationale underpinning the establishment of the EURODEER initiative twelve years ago (Cagnacci et al. 2010). Indeed, such large-scale research is particularly valuable in the case of large carnivores, since conservation planning for these species requires information crossing regional and/or national boundaries. To enable such research, multi-population datasets across environmental gradients are a prerequisite. Specifically, standardised animal and environmental datasets across large spatial extents providing high spatial and temporal resolutions are most useful. Satellite telemetry is well suited for such an approach as the data are relatively simple, consisting of just geographical coordinates and a timestamp at its most basic level. In addition, satellite remote sensing platforms such as the Landsat and Sentinel satellites can provide a variety of standardized products describing the habitat and environmental conditions across large areas, overcoming the limited comparability of local approaches (Oeser et al. 2019). Moreover, spatial databases are needed to store the data (Urbano et al. 2010). However, technical advancements are rendered unimportant when a close collaboration between different research groups is missing, which is able to take advantage of the opportunities provided by technology.

To overcome this shortfall, EUROLYNX was founded – a collaborative scientific initia-tive for data and knowledge sharing on movement ecology of Eurasian lynx. Its aim is to investigate variation in Eurasian lynx behavioural ecology along environmental and climatic gradients and to record population responses to specific conditions, such as habitat changes, impact of human activities, and different prey density and distribution.

EUROLYNX is part of EUROMAMMALS, an umbrella platform that coordinates species-specific projects on European populations of roe deer *Capreolus capreolus* EURODEER, red deer *Cervus elaphus* EUREDEER, wild boar *Sus scrofa* EUROBOAR, and European wildcat *Felis silvestris* EUROWILDCAT. Currently, EUROMAMMALS promotes collaborative science among 100 research groups from research institutes, wildlife offices, protected areas and NGOs with scientific purposes from 30 countries. EUROMAMMALS is supported by an external sponsor and by the voluntary contributions of each partner.

Structurally, EUROLYNX is a database that serves as a repository where data from partner institutions are harmonised, stored and shared for analyses. The EUROLYNX database is hosted on the server of Fondazione Edmund Mach – Centro Ricerca e Innovazione (Italy). The database is constructed to include data at the individual level (GPS and VHF locations, activity data, etc.), the site level (prey density, management, food composition etc.), population level (survival, mortality, genetic structure, etc.), and any other specific data partners believe necessary to be included in the dataset (e.g. body mass, reproductive success, personality, etc.). Furthermore, animal data are automatically annotated with environmental data within the database. These include the Normalized Difference Vegetation Index (NDVI), tree cover density, snow cover, human footprint index, road networks, and land cover. A detailed description of the database can be found in Urbano & Cagnacci (2014). The strength of the database's approach is the standardisation of data among the different research groups, allowing seamless analysis. Through the use of processing protocols and automated as well as manual quality checks, the standardisation also improves data quality. In addition, the database assures long-term data preservation. This is especially important for research groups or PhD students who do not work solely on lynx. In both cases, the data might disappear after a thesis or project report is written. Therefore, it is also on the agenda of EUROLYNX to recover old data and make it available through the database. Moreover, the database also allows collaboration with other large e-infrastructures such as Movebank (Kranstauber et al. 2011) and most importantly, strengthens the links between the different groups working on Eurasian lynx. To ensure this collaboration, each group must agree to specific rules which regulate the way the groups will work together. These "Terms of Use" must be understood and signed by every group that wants to join EUROLYNX.

Fig. 1. Participants of the second EUROLYNX workshop at the Mammal Research Institute Polish Academy of Science, Białowieża, Poland.

EUROLYNX Taking Action

The initiative was founded at a workshop, which took place at the Bavarian Forest National Park, Germany, 15–17 October 2018. In the first year, the activities were focused on setting up and preparing the web page and database as well as dealing with basic communication tasks, organising terms of use documents from partners, website account management, preparation of data templates, database table preparation and data collation. Furthermore, the data curators attended a training workshop at the Fondazione Edmund Mach to learn data curatorship from the core EUROMAMMALS team. The second EUROLYNX workshop was hosted at the Mammal Research Institute of the Polish Academy of Science in Białowieża, Poland 28–30 October 2019 (Fig. 1). Funding for the first year was secured from WWF-Poland and Bund für Umwelt und Naturschutz Deutschland (BUND). The third workshop was held digitally from 7–8 October 2020 due to the corona pandemia, but allowed attending to more than 70 members and students. Moreover, data curatorship was supported by a grant from WWF Germany through the Euro Large Carnivore Project.

During the two workshops, the following working groups have been established:

1) Drivers of survival and mortality of Eurasian lynx in European landscapes

The objective of this working group is to determine European-wide threats to lynx populations. Therefore the working group analyses survival and causes of mortality across ecological and human disturbance gradients The working group is led by the PhD student Joe Premier, University of Freiburg, Germany.

2) Assessing Eurasian lynx habitat in Europe using cross-population wildlife tracking data

The objective of this working group is to produce a continental wide habitat suitability map for Eurasian lynx. Therefore the work-

Fig. 2. Location of the 41 member groups from 19 countries of the EUROLYNX network (see also Supporting Online Material Table SOM T1).

ing group will test the usefulness of GPS telemetry data from lynx populations across Europe. The goal is to identify – based on a systematic model transferability assessment – habitat models that are transferable across ecological gradients while capturing local responses. The working group is led by the PhD student Julian Oeser, Humboldt-Universität zu Berlin, Germany

3) Home range selection of Eurasian lynx populations across landscape gradients

The objective of this working group is investigating the effect of sex-specific behaviour and population density on the 2nd order habitat selection. Specifically, they analyse if males are less selective as they need to cover larger areas, whereas females select higher-quality home ranges to raise and protect their kittens. Moreover they will evaluate if with the animals prefer lower human presence, in the home range core. The working group is led by the MSc student Lucia Ripari, Università degli Studi di Torino, Italy.

4) Harmonisation and standardisation of Eurasian lynx camera trapping

The objective of this working group is to standardise camera-trapping protocols for abundance and density estimates of Eurasian lynx to allow a straightforward comparison of estimates between study areas. Therefore, the influence of sampling design, variables recorded in the field, different analytical approaches, inclusion of covariates and telemetry data will be analysed. The working group is led by Fridolin Zimmermann, Kora Switzerland and Kirsten Weingarth, Habitat – Wildlife Services, Austria.

5) Machine learning (ML)-based pattern recognition via Convolutional Neural Networks in order to identify individual Eurasian lynx captured by camera traps on the basis of their distinctive coat patterns

Currently, thousands of photographs of captured lynx individuals are processed manually and require considerable human effort and time to be analysed visually. This method of individual identification is a tedious, time-consuming task, inducing bias related to the observer. Therefore, we plan to implement a ML-based approach by training a Convolutional Neural Network within the Python (KERAS/Tensorflow) programming environment. The resulting algorithm should assist in processing and analysing collected data and allow for accurate (semi)automatic individual image classification of Eurasian lynx. The working group is led by Robert Behnke, University of Veterinary Medicine Vienna, Austria.

6) Effects of human disturbance on lynx activity patterns

Understanding the activity and habitat requirements of large carnivores, in regard to human disturbance, is a fundamental piece of information for developing effective conservation and management actions. Therefore, we plan to analyse the spatial and temporal tolerance of lynx regarding human disturbance across Europe's ecological gradients. Our main objectives are to identify the forms of human disturbance with greater impact on lynx activity patterns across Europe and to establish if spatial or temporal patterns of lynx activity adjust to the existence of long-time disturbances. The working group is led by Julie Louvrier, Leibniz Institute for Zoo and Wildlife Research, Germany.

7) Movement ecology of Eurasian lynx in relation to foraging behaviour

The working group aims to analyse lynx movement patterns in respect of their foraging ecology at the continental scale, across different landscapes in Europe. Specifically, the questions addressed in this working group are: how does lynx kill rate, feeding and searching times change across Europe and what determines the temporal and spatial distribution of kill sites? The working group is led by the PhD student Teresa Oliveira, University of Ljubljana, Slovenia.

8) Movement ecology of Eurasian lynx during the reproductive season

Research on lynx ecology during the breeding season has mainly focused on den site selection, while less information is available about changes in movement patterns during the mating and denning seasons. This working group will try to fill this knowledge gap by asking how sex-specific movement patterns change during the mating period and how females use space while nursing immobile kittens. PhD student Teresa Oliveira, University of Ljubljana, Slovenia.

9) Shall I cross? What drives spatiotemporal patterns of road crossings and vehicle collissions of lynx throughout Europe

The objective of this working group is to shed light on the poorly understood behavioural response of Eurasian lynx towards roads at different spatial scales. The working group wants to predict spatiotemporal road crossing behaviour and to compare these crossing sites with lynx-vehicle collisions. Therewith they want to provide knowledge on the habitat and roadside characteristics that influence the outcome of road crossings and to predict spatiotemporal "hot-spots" of felid vehicle-collisions. The working group is led by Matteo Bastianelli, Bavarian Forest National Park, Department of Visitor Management and National Park Monitoring, Germany.

10) The timing and synchrony of birth in Eurasian lynx

In contrast to most felid species lynx are strict seasonal breeders. The timing of birth is thus most likely crucial to match weaning with a period rich in resources. This working group is aiming to disentangle the mechanism behind the timing and synchrony of birth in lynx. They expect that lynx in northern latitudes will have a later timing and a shorter birth period due to more extreme climates than lynx in more southern latitudes.

11) Dispersal in human-dominated landscapes

For the conservation of large predators in human-dominated landscapes, understanding the process of dispersal is of great importance. This is especially true for Eurasian lynx, which still occurs in small isolated populations in much of its range. Dispersal plays a key role to achieve connectivity between these populations, allowing genetic exchange. This working group will analyse the movement of dispersers with step selection functions to obtain a better understanding about the requirements of subadult lynx towards human dominated landscapes.

Summing up, in the first years after establishment, we were able to establish the central infrastructure and motivate many groups to join the EUROLYNX-network (Fig. 2). The database contains 680 animals and over 390,000 GPS and 74,000 VHF positions. Also a data table to collect kill series and animals found dead is implemented. Now, EUROLYNX connects a large part of the European community working on Eurasian lynx, thus facilitating their cooperation. During the next years, the focus will be on the integration of further data sets such as genetics and food composition and on the funding of PhD students to facilitate the analysis of data and the cooperation with other cat networks world wide In parallel, we must secure baseline funding for the data curation and the development of the databases. In addition, the first scientific publications are expected for 2021. EUROLYNX will also work on the definition of protocols and standards for future data collection and will foster the identification of gaps in research knowledge to focus the next generation of fieldwork on filling these gaps to secure lynx survival.

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Supporting Online Material SOM Table T1 is available at www.catsg.org.

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Radio-collared lynx collecting data for movement analyses with the EUROLYNX network (Photo KORA).

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Health surveillance in wild felid conservation: experiences with the Eurasian lynx in Switzerland

Switzerland has become an important source of Eurasian lynx *Lynx lynx* for reintroduction projects in Europe. It is now widely accepted that translocations of animals are associated with a serious health risk. Therefore, the development of multidisciplinary expertise and the elaboration of veterinary protocols are needed, which require knowledge on the health status of the source population and information on potential health risks at the release site. Here, both disease cases and carriers of potentially threatening pathogens have to be taken into consideration. In Switzerland, a range of infectious agents circulate within lynx populations apparently without associated morbidity. However, genetic analyses combined with health investigations have pointed at a possible inbreeding depression. Furthermore, unexpected health issues arose in the framework of translocations. Overall, the Swiss experiences underline the necessity of long-term health surveillance of reintroduced and small isolated wildlife populations, the usefulness of well-established veterinary protocols in the framework of translocation projects, the value of multidisciplinary collaborations and of sample archives for further analyses, and the need for adaptive management based on scientific data. For a conservation programme of the Eurasian lynx on a pan-European level, procedure harmonisation should be sought.

Defaunation is a rather new term that aims at raising awareness for the ongoing unprecedented species loss worldwide (Dirzo et al. 2014). Attempts to counteract this dramatic phenomenon include conservation efforts through species reintroductions and population reinforcement (Seddon et al. 2014). However, it is now widely accepted that translocations of animals are associated with a serious health risk (Daszak et al. 2000, Kock et al. 2010) because relocation of an animal always entails relocation of a "biological package" (the animal together with its "passenger organisms"). Further health aspects to consider in this context are stress-induced increased susceptibility to disease and injuries associated with capture, transport, and confinement in a quarantine enclosure. Here, not only health but also animal welfare requirements must be fulfilled (Kock et al. 1999, Kock et al. 2010, Ryser-Degiorgis 2009a). Additionally, genetic considerations are required, particularly when dealing with populations arising from only a few individuals (Trinkel et al. 2011, Brambilla et al. 2015, Pelletier et al. 2017, Grossen et al. 2018, Bozzuto et al. 2019). The development of veterinary protocols requires knowledge on species susceptibility to infection and disease, causes of mortality and health risks, both in the source population and at the release site, including non-infectious health issues such as inbreeding depression. The prerequisite to access this information is the existence of a health surveillance programme for the species of interest, consisting at least in necropsies of dead animals as well as pathogen and serological surveys, especially at the source (Ryser-Degiorgis 2009a).

The Eurasian lynx was reintroduced to Switzerland in the 1970s. Meanwhile Switzerland is considered having a great responsibility regarding the conservation of the Alpine lynx population (Zimmermann et al. 2011), and the two Swiss lynx populations (one in the Alps, the other in the Jura Mountains; Breitenmoser et al. 1998, Chapron et al. 2014) have become an important source for reintroduction and reinforcement projects in neighbouring countries. The aim of this article is to share the implemented procedures and acquired experience in the framework of the veterinary supervision of lynx translocation in Switzerland (2000–2020).

Lynx health surveillance programme in Switzerland

Surveillance of lynx health in Switzerland has been carried out for several decades, implying the close collaboration of veterinarians, biologists, wildlife managers and museums. The programme currently in place includes (1) the pathological examination of all lynx found dead (whether diseased, poached or traffic-killed). Carcasses may be found by chance or recovered thanks to radio-tracking; and (2) the clinical examination of live lynx (orphans and older animals captured for management, conservation or research purposes).

The costs of post-mortem investigations have been covered by the long-term mandate of the Swiss Federal Office of the Environment (FOEN) to the Centre for Fish and Wildlife Health (FIWI) at the University of Bern for general surveillance of wildlife health in Switzerland (Ryser-Degiorgis and Segner 2015). The FOEN has also supported the lynx population monitoring carried out by the Foundation KORA (Carnivore Ecology and Wildlife Management) and attributed mandates to both the FIWI and KORA for the translocation programmes. Research grants have additionally contributed to capture costs and genetical analyses, and the laboratory analyses have been supported by the Clinical Laboratory of the University of Zurich. An additional contribution has consisted of non-remunerated personal investment by multiple collaborators.

Morphological data, pictures of the coat patterns and samples such as blood are collected from both dead and live animals. Faeces from live animals are collected from the ground, either in the field (on tracks or around a prey of radio-marked animals) or during quarantine. Samples are subsequently analysed and/or archived. Tentative rehabilitation of lynx orphans has been carried out for decades, with disappointing results. The main limitations have been the political situation hindering releases into the wild, the lack of appropriate enclosures, captivity stress resulting in severe teeth damages, and post-release issues such as traffic accidents or predation on domestic animals. Independent diseased lynx were either treated in the field and released on site (two cases affected by sarcoptic mange) or euthanised in quarantine because of severe debilitation (two cases with suspected Feline Immunodeficiency Virus (FIV) infection; Ryser-Degiorgis et al. 2017).

Dead lynx

Post-mortem examinations on Eurasian lynx found dead, culled or euthanised in Switzerland have been carried out since the 1970s (earliest reports in the FIWI archives) and the necropsy findings compiled from 1987

(Schmidt-Posthaus et al. 2002). An extended necropsy protocol including sample collection for systematic histological analyses (collection of baseline data) and for archive purposes was introduced in 2002. The 2004 update of the official management plan (Swiss lynx concept, originally implemented in 2000), required the submission of all dead lynx to a single institution (FIWI). Since then, the FIWI has been officially responsible for lynx veterinary examinations and for hosting a sample archive.

Necropsy and sampling protocols have been improved over years. The current protocol includes the following steps (Fig. 1): lynx are photographed on both sides to record the individual coat pattern to identify individual animals for comparison with photo-trapping data (Thüler 2002, Pesenti & Zimmermann 2013), sex and body condition are determined, the body weight is recorded, and standard morphological measurements are taken (Marti & Ryser-Degiorgis 2018b). Age is estimated mainly based on dentition, tooth wear and body size (Fig. 2; Marti & Ryser-Degiorgis 2018a, 2018b) but also considering maturity of genital organs and season. All animals are systematically radiographed to search for foreign bodies such as ammunition fragments and for skeletal anomalies. After complete skinning according to museum instructions for subsequent taxidermic preparation, a thorough gross necropsy is performed without damaging the skeleton. A careful macroscopic inspection of the thoracic and abdominal cavities as well as of all internal organs is carried out; pictures of any abnormality are taken. Weight and other morphological data of selected organs are collected, and multiple organ samples fixed in 4% buffered formalin for histological examination. Additional native samples (blood, selected organs) are stored frozen at -20°C for genetic analysis and at both -20°C and -80°C for archive purposes. The brain is only collected if required to achieve a diagnosis, after consultation and agreement of the local hunting authorities who submitted the case (otherwise, skeletons are left intact for taxidermy). Samples of the diaphragm, tongue and/or masseter muscle, as well as faecal samples from the rectum, are immediately submitted to parasitological examination, namely for the search for *Trichinella* sp.

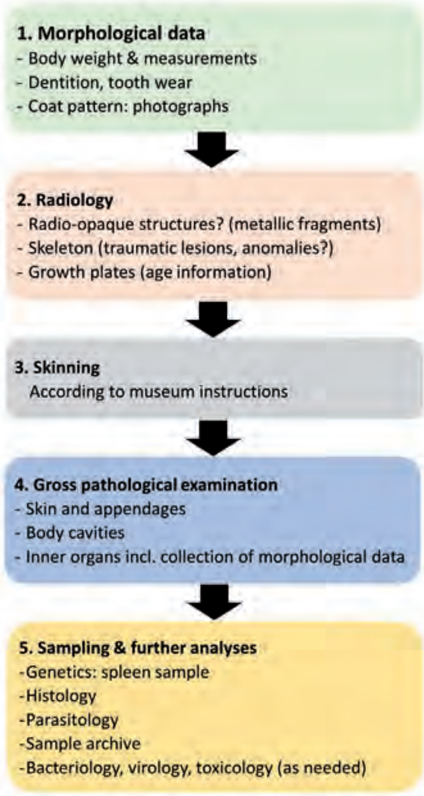

Fig. 1. Necropsy protocol for Eurasian lynx established at the Centre for Fish and Wildlife Health, University of Bern, Switzerland.

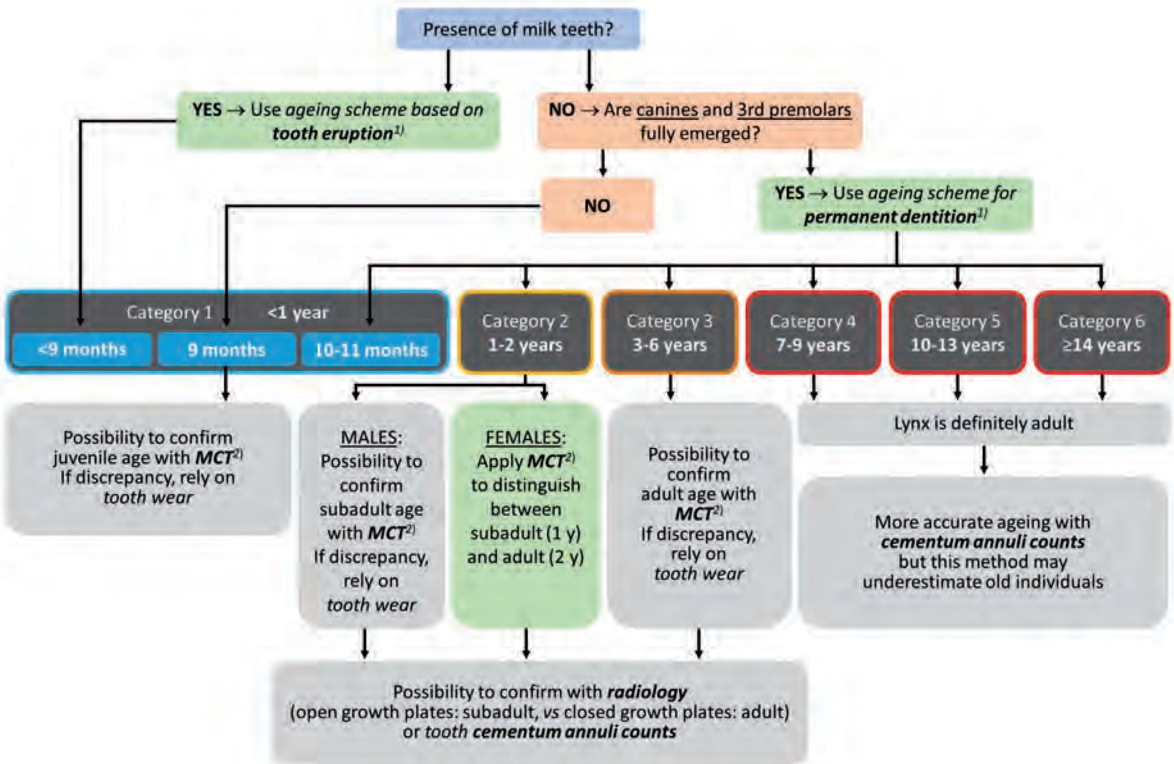

Fig. 2. Decision tree to determine the age of Eurasian lynx (developed for *Lynx lynx carpathicus* in Switzerland). [1)] Marti and Ryser-Degiorgis 2018a (age estimation based on tooth eruption and tooth wear); [2)] MCT = morphology classification tree described in Marti and Ryser-Degiorgis 2018b (age estimation based on morphological measurements). These two methods have the advantages that they are noninvasive, costless, deliver immediate results, and can be applied both intra-vitam and postmortem, in any working place. Green boxes are necessary steps, light grey boxes correspond either to possible confirmatory steps or to a more accurate but invasive ageing procedure.

(Frey et al. 2009) and for gastrointestinal helminths and protozoa, respectively. If necessary, bacteriological, virological or toxicological analyses are initiated to determine the cause of death.

Live lynx

A procedure similar as that applied to dead lynx is used for live lynx, starting with the collection of morphological data including body weight and photographs of the coat pattern (Fig. 3). Blood has been collected for genetic analyses since 1993. Since 1997, additional blood samples have been taken for health investigations and archiving. Since 2000, a thorough clinical analysis and close anaesthesia monitoring has been performed on every lynx manipulated alive (Supporting Online Material Figure SOM F1). The corresponding data have been recorded on paper and the main information transferred into a digital database. Since 2013, heart sounds have been recorded by means of an electronic stethoscope with record function (3M™Littmann® 3200; https://www.littmann.com/3M/en_US/littmann-stethoscopes/), and since 2018 echocardiographies have additionally been performed, using a portable ultrasound device (Logiq_e BT12 with transducer 3S-RS (1,5–4,0 MHz), scil animal care company GmbH, Germany; SOM F2). Blood samples

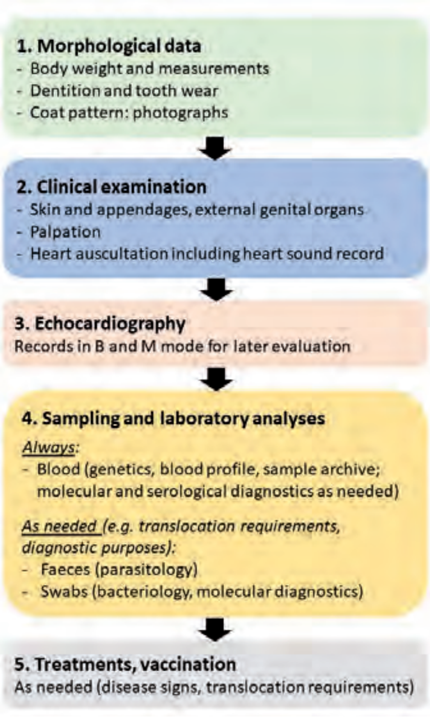

Fig. 3. Capture protocol for Eurasian lynx in Switzerland with focus on veterinary procedures. Details on samples, blood profile and molecular diagnostics are given in Table 1.

and by necessity (according to clinical signs or translocation protocols) other clinical samples (e.g., oropharyngeal, conjunctival or rectal/faecal swabs) have been sent to the Clinical Laboratory of the University of Zurich for immediate analysis (haematology, blood chemistry, serology, and molecular methods for pathogen detection).

Lynx protocols for translocation

The first translocation project of Eurasian lynx from Switzerland (2000–2008) aimed at reintroducing animals in an area within country borders (Ryser-Degiorgis et al. 2002a, Zimmermann et al. 2011). Subsequently, a few lynx were translocated to Austria for population reinforcement (2011, 2013 and 2017: www.kalkalpen.at/de/Luchse_in_den_OOe_Kalkalpen) and Italy (2014: Molinari et al. 2021), followed by a larger reintroduction project to southern Germany (2016–2020: Idelberger et al. 2021). Crossing national borders implied the fulfilling of additional requirements by international regulations (Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES) and the veterinary authorities of the destination countries. Over the years, health protocols have evolved based on the acquired experience and on the health and genetic data collected.

Disease susceptibility of Eurasian lynx

Firstly, the available published and grey literature was reviewed, completed by personal communications from ongoing studies or unpublished data, to provide an overview of the knowledge on pathogens potentially affecting or carried by lynx (Ryser-Degiorgis 2001, 2009b, Ryser-Degiorgis et al. 2002a).

The main disease of concern was sarcoptic mange, which emerged in lynx in the Swiss Alps in the late 1990s (Ryser-Degiorgis et al. 2002b, Schmidt-Posthaus et al. 2002, Munson et al. 2010). This disease is typically observed in lynx in geographical areas where mange affects the local fox population (Ryser-Degiorgis 2009b, Munson et al. 2010) but at the time there was no mange epidemic in red foxes *Vulpes vulpes* in the release area in north-eastern Switzerland (Pisano et al. 2019). No specific bacteria was of particular concern (Ryser-Degiorgis 2001, 2009b) but feline viruses (Table 1) were considered a potential threat, considering their significance in both domestic and wild felids (Lutz 2005; Leutenegger et al. 1999, Meli et al. 2009). The emphasis on mange and viruses in the health screening of wild felids to be translocated is also recommended by international organisations (International Union for the Conservation of Nature, IUCN; World Organization for Animal Health, OIE; and European Association of Zoo and Wildlife Veterinarians, EAZWV; Woodford 2000).

Disease risk in the destination environment

Secondly, information was gathered on potential health risks associated with the destination environment. This was most difficult to access, as documentation (scientific literature, unpublished project reports) was poor or non-existent. Consequently, the risk evaluation in foreign countries largely relied on the official epizootic disease status of the concerned country and personal communications from project partners. Nevertheless, for the first project within Switzerland (2000–2008), data on prey species from the general wildlife health surveillance programme were taken into account, and for the last project (Germany, 2016–2020), the release area being in geographical continuity with the source population, it was assumed that the risk of pathogen exposure would be comparable to the situation in the capture area.

Criteria for translocation

The selection of individuals aims at: (1) preventing the introduction of lynx either clinically diseased or carrying pathogens representing a potential threat to other lynx, other animals (wild or domestic) and humans at the release site [Figs 4 and 5 (1)]; (2) increasing the chance of survival of the individuals being translocated [Fig. 5 (2a, 2b)]; (3) increasing the chances of reproduction of the released lynx after translocation; and (4) optimizing the genetic pool of lynx moved for reintroduction or reinforcement. These four aspects refer to health both on an individual (1, 2, 3) and on a population level (1, 3, 4). Further important health considerations on an individual level include acting with respect of animal welfare, i.e., selecting appropriate methods for safe and effective capture/anaesthesia, stress management and maximal possible reduction of the risk of injuries.

Criteria for selection revised in 2015 include the absence/presence of disease signs or other abnormal observations at clinical examination, the estimated age (based on the methods described for dead lynx, see above), the genetic profile of the animal, and the results of diagnostic analyses (haematology, blood chemistry, coprology, and pathogen

Table 1. Testing scheme for Eurasian lynx to be translocated from Switzerland. Since the purpose is, on the one hand, to assess the health status of each individual, and on the other hand, to prevent the "export" of infectious agents potentially relevant to the (new) population at the release site, investigations target mainly direct pathogen detection rather than antibodies, because antibodies indicate past or present exposure of the individual to the microorganism(s) but do not deliver information on its current infection status.

Parameter	Target	Sample	Details/methods
Blood profile	Haematology	EDTA whole blood + fresh thin blood smears	Complete blood cell count and white blood cell differential
	Blood chemistry	Serum	Chemistry profile parameters*
FeLV[1]	Free FeLV p27 antigen	Serum	ELISA[2]
	FeLV whole virus (FL74) and/or FeLV p15E antibodies	Serum	ELISA
	Proviral DNA	EDTA whole blood	Real-time TaqMan qPCR[3]
FIV[4]	FIV antibodies	Serum	FIV-Westernblot
Feline Herpesvirus	Viral DNA	Conjunctival swab	Real-time TaqMan qPCR
Feline Calicivirus	Viral RNA	Oropharyngeal swab	Real-time TaqMan RT[5]-qPCR
Canine Distemper Virus	Viral RNA	Oropharyngeal swab	Real-time TaqMan RT-qPCR
Feline Parvovirus	Viral DNA	Rectal or faecal swab	Real-time TaqMan qPCR
Feline Coronavirus	Viral RNA	Rectal or faecal swab	Real-time TaqMan RT-qPCR

[1] FeLV: Feline Leukaemia Virus. [2]ELISA Enzyme-linked immunosorbent assay. [3] qPCR: quantitative polymerase chain reaction. [4] FIV: Feline Immunodeficiency Virus. [5] RT: reverse trancriptase. * Parameters: total bilirubin, glucose, urea, creatinine, total protein, albumin, globulin, cholesterol, triglycerides, alkaline phosphatase, alanine aminotransferase, aspartate aminotransferase, lipase, creatine kinase, calcium, phosphorus, sodium, potassium, chloride

screening as presented in Table 1). The selection of animals is a process that takes place in two steps (Fig. 6). A first selection occurs in the field after examination at the capture site. Animals considered suitable for the translocation programme are moved to quarantine facilities.

During quarantine, lynx are observed by video-surveillance while their samples are tested in the laboratory (blood and genetic profiles, selected infectious agents and endoparasites). Depending on the results, the lynx will either qualify for immediate translocation, or may undergo additional testing and a prolonged observation period, and/or receive a specific treatment. In some cases, repatriation to the original capture site or even euthanasia may have to be considered (Fig. 6). During the first translocation project (2000–2008), quarantine duration used to be 2–3 weeks. Others recommend a minimum of 30 days for wild felids (Woodford 2000). However, experience showed that quarantine duration shall be reduced to a minimum because of the considerable stress experienced by lynx caught in the wild and the resulting self-inflicted injuries when they are kept in captivity. Besides improvement of the enclosures (size, structure, materials, sliding doors between adjacent enclosures, video-surveillance), nowadays the quarantine lasts only until all laboratory results are available and the release logistics (border paperwork, transport to release site) is set up; all this takes about a week.

Field procedures

Lynx are captured with foot snares, box traps or a remote-controlled injection system as previously described (Breitenmoser et al. 2014, Ryser et al. 2005, Vogt et al. 2016). Until 2019, subadult and adult lynx were anaesthetised with an intramuscular injection of medetomidine hydrochloride (Domitor®, Orion Corporation, Espoo, Finland) in the rear muscles of a hindleg, followed by ketamine hydrochloride (Ketasol®-100, Dr. E. Gräub AG, Bern, Switzerland) 15–20 minutes later. Since the weight of the animal is not known before anaesthesia, lynx were administered a standard dose of 2.8 mg medetomidine and 80 mg ketamine (i.e., approx. 0.13–0.17 mg/kg medetomidine and 3.6–5.0 mg/kg ketamine depending on the weight; Marti & Ryser-Degiorgis 2018a). This is normally sufficient for a safe anaesthesia until the end of the manipulations. If necessary 0.1–0.2 mg medetomidine and/or 10–20 mg ketamine was subsequently injected in the shoulder musculatur. Atipamezole hydrochloride (Antisedan®, Orion Corporation, Espoo, Finland) at a dose of five times the medetomidine dosage (in mg) was used as an antagonist for medetomidine and was injected at least 1 hour after the last ketamine injection. The effect of ketamine can last up to approximately 1 hour and cannot be antagonised. If medetomidine is antagonised too early, there is a risk of rough recovery due to the residual effects of ketamine (Kreeger & Arnemo 2007). Drug injection in the shoulder results in faster absorption (Kreeger & Arnemo 2007), which can be useful in emergency situations. Besides emergencies, our experience has shown that shoulder injections are efficient for drug supplementation during manipulations (see above). However, for recovery under normal conditions, antagonist injection in the hind leg musculature is preferable because it results in a smoother recovery than if the drug is administered in the shoulder muscles. This anaesthesia protocol is well established and no adverse effects have been recorded, neither in previous studies (Vogt et al. 2016) nor in the past few years. However, since 2020, a single intramuscular injection of 2.2 mg medetomidine mixed with 80 mg ketamine

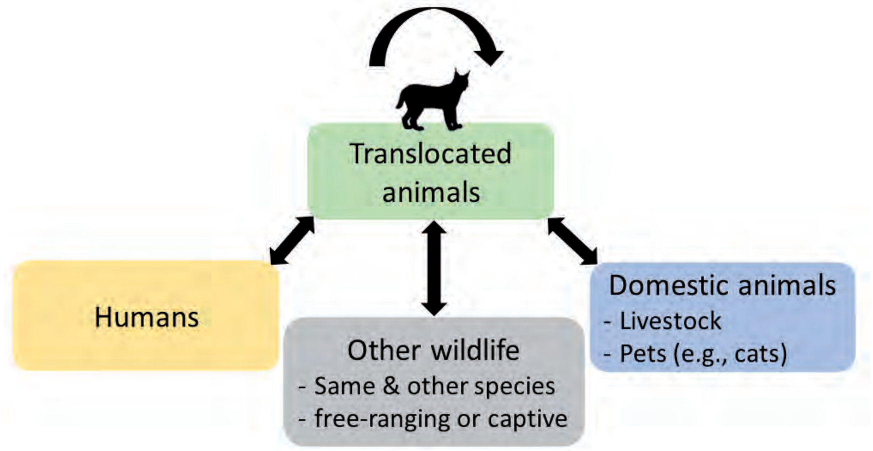

Fig. 4. Health risks associated with lynx translocations at population level. Moved wild animals can bring microorganisms or deleterious genes to the destination environment, which may cause disease in individuals of the same species, in other wildlife, in domestic animals or in humans.

has been used per lynx to reduce the induction time, followed by the same procedure for reversal as before. This new protocol has been used for only a few lynx so far but appears to be promising.

During anaesthesia (SOM F2), respiratory rate, heart rate, pulse rate, mucous membranes (capillary refill time and colour), rectal temperature and reflexes are continuously monitored by a person previously designated for this task. Blood oxygen saturation is measured with a portable pulse oximeter (Pulse Oximeter, CONTEC Medical Systems Co., LTD, Qinhuangdao, China). All values and observations are recorded in an anaesthesia datasheet. The most critical point encountered during field anaesthesia of lynx has been related to the body temperature, namely hypothermia during cold days, especially in rainy or snowy weather and hyperthermia at mild environmental temperatures. In these situations, prevention is crucial as it is very challenging to reverse the development in one direction or the other. Details on manipulation and emergency procedures can be found elsewhere (Breitenmoser et al. 2014, Kreeger & Arnemo 2007).

Captured animals are examined clinically, with particular attention to their general appearance, body condition, size and weight, tooth wear and genitals. Animals in a normal body condition (considering that adult males may be thinner during the mating season than at other times of the year), aged more than one year but no more than 13 years old, and without significant clinical abnormalities (such as a recent fracture, infected wounds, mange lesions, a heart murmur or a potentially inherited malformation such as cryptorchidism), are considered as adequate for a transfer to quarantine facilities (Fig. 6). By contrast, obviously old lynx (based on tooth wear, e.g., severely worn or discoloured teeth; Marti & Ryser-Degiorgis 2018b), lynx with a heart murmur or a nonlethal malformation of potential genetic origin, are directly released on site; those with a heart murmur may be radio-collared to follow the evolution of their condition and to eventually recover their carcasses for pathological examination. Lynx younger than one year or presenting a disease or trauma with good chances of healing (e.g., mange after appropriate treatment) may be released on site with a GPS collar to be re-captured at a convenient time. In some cases, a transfer to the quarantine station for more intensive care may be considered. However, animal welfare aspects must be taken into account (e.g., stress induced by transport and captivity may have a negative impact on health), as well as the risk that an animal suffering from an infection may represent to other lynx already present in the quarantine facility (although this risk largely depends on the building structure and quarantine management).

All lynx selected for translocation receive an antiparasitic treatment (single subcutaneous injection of praxiquantel: Caniquantel pro Inj., Dr. E. Gräub AG, Berne, Switzerland, at a dosage of 5.68 mg/kg; and of doramectin: Dectomax®, Elanco Tiergesundheit AG, Basel, Switzerland, at a dosage of 1 mg/kg; this doramectin dosage has led to a full recovery of lynx heavily affected by mange; Ryser-Degiorgis 2013) to reduce the risk of translocating apparently healthy lynx infested with mange mites (early disease stage or healthy carriage; Munson et al. 2010) and in the hope to decrease their helminth burden (Woodford 2000), which may have a greater health impact under stressful conditions. Any necessary wound treatment is made at this time point. Other medication (including antibiotics) is not administrated unless it appears appropriate based on the clinical findings. Vaccination is only foreseen if authorities of the recipient country require it. The rationale behind this decision is that (1) vaccination provides protection only for a limited amount of time; since both repeated vaccination boost(s) and systematic vaccination of offspring are unpracticable in a free-living population, animals unable to cope with the infection risks in

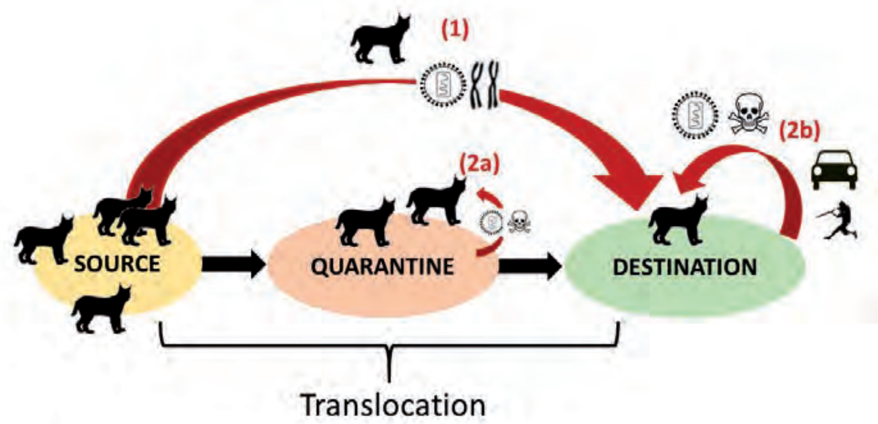

Fig. 5. Health risks associated with lynx translocations include the potential introduction of a pathogen (infectious agent with the potential to cause disease) or deleterious genes into the destination population (to be reinforced or reintroduced) by the animals being translocated (1); and the potential transmission (by other animals or the environment) of a pathogen new to the lynx being translocated as well as the exposure to toxic compounds from the environment or other non-infectious causes of disease or mortality during (2a) or after (2b) the translocation process.

their new environment would not survive on the long term; and (2) vaccination with inactivated vaccines offer only limited protection, while the use of live vaccines in wildlife species may cause disease or even death (Connolly et al. 2015).

All captured lynx are marked with a subcutaneous transponder (microchip; DATAMARS, https://datamars.com/) implantation in the midway region on the left side of the neck (according to the standards of the Global Veterinary Community for domestic cats and other companion animals in continental Europe; https://www.wsava.org/Global-Guidelines/Microchip-Identification-Guidelines) and blood-sampled. Pharyngeal, conjunctival and rectal dry swabs are collected. In recent years a point-of-care test (i.e., a fast field test) for Feline Immunodeficiency Virus (FIV) antibody and Feline Leukaemia Virus (FeLV) antigen detection validated for domestic cats (SNAP FIV/FeLV Combo Test, IDEXX, Switzerland) has been used in the field, as the selection criteria foresee to exclude individuals with a positive result. However, experiences with testing for FIV in 2016 and 2017 have shown that this fast field test may deliver false negative results when applied on lynx samples and that testing in the laboratory is required to obtain reliable data on FIV infection. As experiences in the Iberian lynx suggest that the test can detect progressive FeLV infections that might end fatally, lynx fulfilling criteria for translocation are brought to quarantine without SNAP testing and tested in the laboratory. Lynx not fulfilling translocation criteria and planned to be released on site should be tested with the SNAP test and taken to captivity in case of a positive result. If a progressive infection is confirmed by laboratory testing, they should be extracted from the population (Meli et al. 2010a).

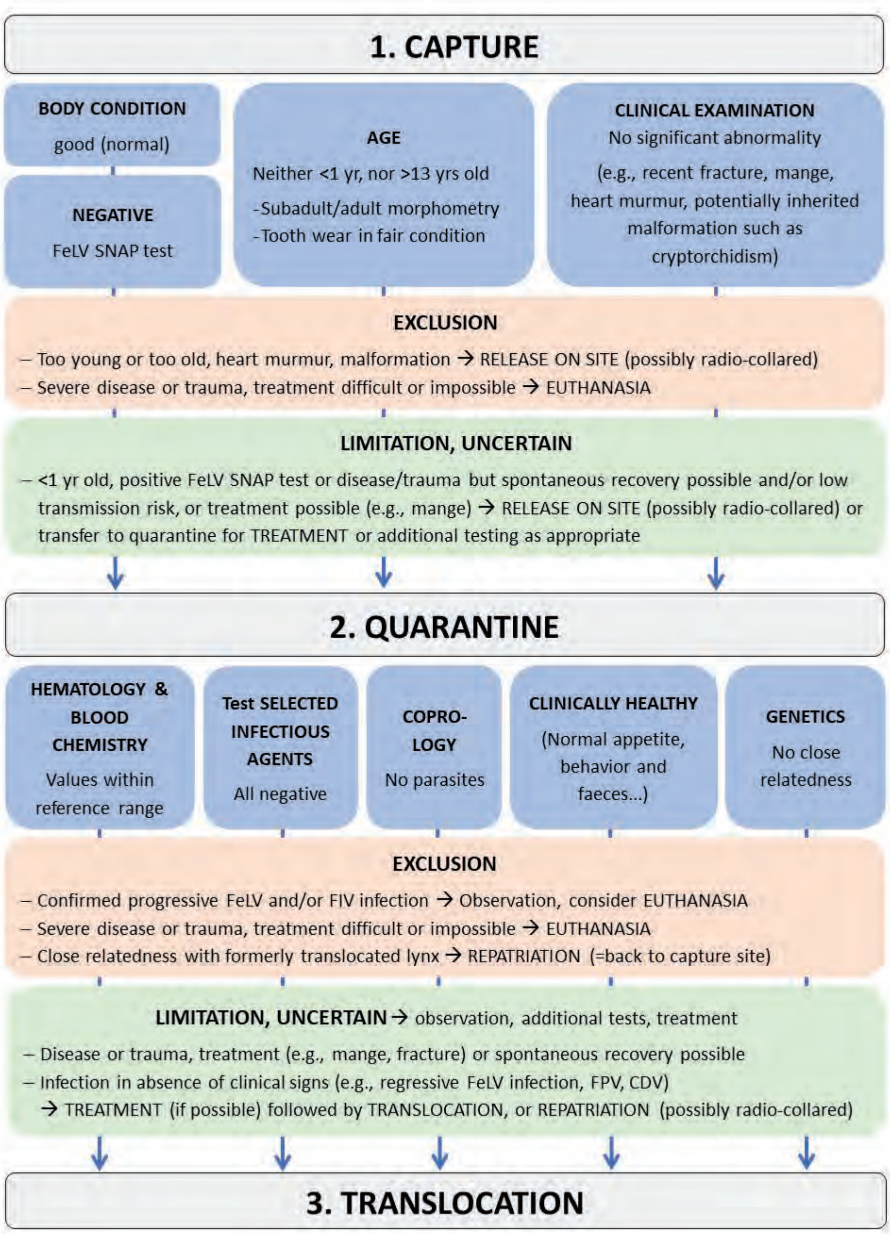

Fig. 6. Selection criteria currently applied for translocation of lynx from Switzerland. FIV: Feline Immunodeficiency Virus; FeLV: Feline Leukaemia Virus; FPV: Feline Parvovirus; CDV: Canine Distemper Virus.

Lynx transport has proven to be a more challenging step than originally thought. If anaesthetised and slowly recovering during transport, constant monitoring of vital parameters is required until recovery, and lynx tend to develop hypothermia even in a heated vehicle. If transported after anaesthesia reversal, lynx might be stressed and thus at risk of injuries (splitted claws, broken teeth, skin abrasion on the forehead) and cardio-respiratory distress (hyperthermia, hyperventilation). However, anaesthesia reversal is preferred, as risks of stress and injuries also concern lynx recovering from anaesthesia during transport and in case of transboundary translocations transport may be very long. There are marked and unpredictable interindividual differences in behaviour and stress-susceptibility but since interventions cannot be performed on a conscious lynx, once more, prevention is key. It is important for humans accompanying the animal during transport to stay quiet (no loud voices or sudden noises) and to cool down the interior of the vehicle. Furthermore, over the years, the transport boxes have been improved to be able to interchange doors without opening the boxes, and thus have the possibility to either keep the animal in the dark (full door) or to improve ventilation (metal bar door) by interchanging door types (SOM F3). Additionally, active ventilation into the box with an external device has had a calming effect on stressed lynx. Extensive general guidelines on the transport of live animals can be found elsewhere (e.g., the "IATA Live Animals Regulations" (LAR), which is the global standard and the essential guide to transporting animals by air in a safe, humane and in a cost-effective manner (https://www.labeline.com/product/iata-live-animal-regulations-lar-46th-edition-2020); and the CITES guidelines for the non-air transport of live wild animals and plants (https://cites.org/sites/default/files/eng/resources/transport/transport_guidelines_2013-english.pdf).

Pre-release procedures

Blood samples taken at capture are analysed in the laboratory. Haematology and blood chemistry values are compared with reference values obtained from clinically healthy free-ranging Eurasian lynx from Switzerland. The first faeces found in the enclosure is collected and analysed for lung and gastrointestinal parasites by coprology. Blood and swab samples are tested by molecular methods and/or serology for selected infectious agents (Table 1).

Based on the data collected in Switzerland since the first lynx reintroductions and on studies published on wild felids elsewhere in Europe, we classified microorganisms potentially occurring in lynx into three risk levels:

(1) High risk: Only infections with FeLV and FIV were considered as a criterion for exclusion, as these viruses had not previously been detected in free-ranging or captive populations of Eurasian lynx and were considered having the potential to seriously harm infected animals (Meli et al. 2009, Geret et al. 2011, Troyer et al. 2011).

(2) Mild to moderate risk: In the case of other agents such as Canine Distemper Virus (CDV) or Feline Parvovirus (FPV), which may cause disease in lynx (Stahl and Vandel 2009, Wasieri et al. 2009, Meli et al. 2010, Origgi et al. 2012) but are also known to occur (FPV PCR-positive, CDV-seropositive) without associated morbidity and mortality in apparently healthy lynx populations, or such as Feline Calicivirus, Feline Herpesvirus and Feline Coronavirus, for which there is serologic evidence of exposure but no known morbidity (Meli et al. 2009; Ryser-Degiorgis and Meli, unpubl.), the clinical status and blood parameters of the animals are more relevant criteria to evaluate their individual health status than the detection of the pathogen. On a population/ecosystem level, the relevance of pathogen detection depends on the harm it may cause at the release site.

(3) Minimal risk: Infectious agents such as *Cytauxzoon* spp., feline haemotropic mycoplasmas and intestinal endoparasites are widespread in clinically healthy lynx (Valdmann et al. 2004, Willi et al. 2007, Millán et al. 2007, Meli et al. 2009, Ryser-Degiorgis et al. 2010a, Deksne et al. 2013) and not expected to be a threat to lynx or to represent a serious risk for other felid species in the framework of Eurasian lynx translocations. Their detection should serve as a documentation for the long-term health monitoring of the source and of the re-introduced populations but is currently not considered a criterion for selection of lynx in the framework of translocations. Therefore, samples for additional tests of scientific value but not relevant to immediate translocation are stored for potential later analysis.

Animals with blood values significantly diverging from reference data or with infections of unclear clinical significance are observed more closely, possibly longer, and submitted to additional testing as appropriate. The genetic profile of all animals is determined during the quarantine period. In case of close relatedness (brother and sister; mother/father and offspring) with other lynx already translocated or simultaneously kept in quarantine for translocation, the animal is excluded from the programme and repatriated to the capture site.

Before transfer to the release site, lynx are anaesthetised to be fitted with a GPS collar and undergo another clinical check before transportation. They are blood-sampled for archive purposes, i.e., no test is performed at this point without a specific indication. If a reason for exclusion (see above) not noticed earlier is detected, experts in charge consider three options: (1) repatriation to the original capture site, (2) prolongation of the quarantine (with treatment as appropriate and subsequent re-assessment), or (3) euthanasia. Radiographs or additional laboratory tests are performed only in case of specific indication. No treatment is administered at the time of release unless indicated by clinical findings. If the suitability of an individual is questionable, the decision whether to translocate it or not is taken together with the project partners in the recipient country.

A summary of the identified health risks and the corresponding management measures is presented in Table 2.

Translocation challenges encountered in Switzerland

Sarcoptic mange was first detected in lynx in Switzerland in 1999 (Ryser-Degiorgis et al. 2002b, Schmidt-Posthaus et al. 2002). At the time, there was no indication of another health issue relevant to translocations in the Swiss lynx population (Ryser-Degiorgis et al. 2002a). More cases of mange were diagnosed since then, including captured lynx that were successfully treated (Ryser-Degiorgis 2013). This occurred simultaneously with the Swiss-wide spread of sarcoptic mange in the red fox (Pisano et al. 2019). Similarly, in the framework of the large canine distemper outbreak that has affected Swiss wildlife since 2009, an infected Eurasian lynx was observed with clinical signs (Origgi et al. 2012). *Cytauxzoon* spp. was found for the first time in a severely debilitated lynx in 2006, but the hypothesis of its causal role was discarded by the pathological examination that followed euthanasia. As the significance of this pathogen was still unclear, raising questions regarding the suitability of positive animals for translocation programmes, a retrospective study on archived samples and systematic testing of lynx to be translocated were initiated, which showed that this haemoparasite is widespread in lynx from Switzerland (Ryser-Degiorgis et al. 2010b). Feline Parvovirus infection (viraemia and faecal excretion) without associated disease signs was first found in an orphaned lynx in 2012, and again in an adult lynx to be translocated to Austria (viraemia only) in 2013 (Ryser-Degiorgis & Meli, unpubl.). In 2017 a lynx was diagnosed with ocular chlamydiosis (Marti et al. 2019), and two animals with unspecific disease signs were suspected to be infected with FIV (Ryser-Degiorgis et al. 2017). In 2019, an apparently healthy male was confirmed to be latently infected with FeLV (detection of proviral DNA and anti-whole virus and p15E antibodies, i.e., regressive FeLV infection) and was repatriated to the capture site fitted with a radio-collar; no disease sign development has subsequently been observed (Marti et al. unpubl.). Concerning non-infectious diseases, sporadic congenital malformations have been observed over the past decades (Morend 2016, Ryser-Degiorgis et al. 2004). Genetic analyses have revealed a loss of variability and increasing inbreeding mainly in the Alps (Breitenmoser-Würsten & Obexer-Ruff 2003). Heart murmurs have increasingly been detected in Alpine lynx since 2001, after a lynx with such a murmur was translocated and died of cardiac failure due to a cardiomyopathy two years after release (Ryser-Degiorgis et al. 2020). A few more fatal cardiomyopathies have been diagnosed since then, and meanwhile there are indications that the observed heart anomalies (murmurs, histological cardiac lesions), whether associated with disease signs or not, may be related to inbreeding (Ryser-Degiorgis et al. 2018). As new knowledge has been gathered on this issue, it has progressively led to the exclusion of individual lynx with heart murmurs from translocation programmes, and since 2015 even of the whole Alpine lynx population. Other aspects of the health screening protocol (selected agents, collected samples and applied laboratory tests) have been improved and selection criteria for individual lynx have been refined (Table 2, Fig. 6). The management of health-relevant findings detected in individual lynx

Table 2. Health risk management in the framework of translocation of free-ranging Eurasian lynx from Switzerland.

Health issue	Risk management
POTENTIALLY INHERITED	
Heart murmurs of potential genetic origin incl. a few fatal cases (Alpine population)	Exclusion of all Alpine lynx as well as individuals from other populations presenting with a heart murmur
Sporadic malformations of various body parts	Documentation of visible anomalies at clinical examination; exclusion if suspected inheritance (e.g., cryptorchidism)
INFECTIOUS	
High risk: FeLV[1], FIV[2] (no infection known in the source population, potential threat to both the source and destination)	Systematic testing; if confirmed positive for FIV or progressive FeLV infection: observation, with additional testing if deemed appropriate, followed by repatriation or euthanasia
Moderate risk: Canine Distemper Virus (moderate disease risk), Feline Parvovirus (low disease risk but cannot be excluded: see Stahl & Vandel 2009), Feline Herpesvirus, Feline Calicivirus and Feline Coronavirus	Systematic testing, decision based on clinical status and re-testing (aim: to minimize the risk of excretion)
Minimal risk: *Cytauxzoon* spp., feline haemotropic mycoplasmas, among other microorganisms (no known cases of clinical disease)	No systematic testing (scientific documentation only and/or surveillance data collection)
Sarcoptic mange (also notoedric, otodectic)	Systematic treatment against mites (aim: to eliminate mites)
Endoparasites (gastrointestinal helminths)	Systematic treatment and testing (aim: to minimize the risk of increase of endoparasite burden and associated apparition of clinical signs potentially resulting from increased stress)
OTHERS	
Any other viral or bacterial infection; ecto- or endoparasitic infestation; trauma; or detection of unspecific disease signs	Treatment if available and appropriate (on medical, financial, logistical and animal welfare points of view), observation of clinical status, additional testing if deemed useful; depending on disease course: translocation, repatriation or euthanasia

[1] FeLV: Feline Leukaemia Virus. [2] FIV: Feline Immunodeficiency Virus

during translocation projects since 2013 is summarized in Table 3.

Detailed records of clinical findings and anaesthesia procedures have contributed to the improvement of capture methods and prevention measures aimed at decreasing capture-related risks. In particular, awareness was raised regarding the elevated risk of injuries when using box traps made of metallic grid, of hypothermia in winter and of hyperthermia during transport as well as when using foot snares in the spring. Already after the first year of the first project (i.e., at the end of 2001), improvements were made to box traps to reduce the risk of injuries at capture and to housing conditions to reduce the risk of injuries and stress during quarantine, followed later on by modifications of transport boxes to reduce the risk of injuries, stress and associated hyperthermia and to provide possibilities to better ventilate and observe the animals during transport. Importantly, as stated above, the duration of the quarantine has been drastically shortened, being now limited to the time required for relevant laboratory results to be available, unless there are indications for a prolongation.

Of the few females diagnosed as pregnant at the end of the quarantine, some gave birth after translocations, others did not, suggesting that the stress caused by transport and release in a new environment, alone or in addition to that induced by the initial capture, first transport and quarantine period (i.e., additive stressful situations), might cause abortion. However, to our knowledge, to date there is no scientific evidence supporting this hypothesis (Vié et al. 1998, Kreeger 2012, Nagel et al. 2019), hinting at a minimal risk of abortion due to translocating procedures. Since the period of the year associated with the highest lynx capture success is the mating season (males on the move for reproduction purposes, snowy landscapes resulting in a higher likelihood for prey to be found and a frequent use of existing paths where box traps are placed), it is inevitable to capture and move potentially pregnant females.

Conclusions

Health risk analysis in the framework of lynx translocations has proven to be an important tool to reduce the risk of project failure, considering that a range of pathogens have been detected, which required case-specific management measures. These experiences have also underlined the importance of a health surveillance programme starting prior to a translocation project and of the usefulness of a sample archive. Furthermore, the lack of data on disease risk at the release sites pointed at the necessity to carry out health surveillance in both domestic animals and wildlife to provide data useful to the planning of species conservation projects.

It is important to remember that it will never be possible to work with zero risk, and that one needs to be ready to experience the unexpected and to show adaptation potential after careful planning. Although not mentioned further here, post-release monitoring not only of the lynx behaviour, reproduction and population genetics but also of health issues (particularly the thorough examination

Table 3. Health issues encountered during capture and quarantine of Eurasian lynx caught for translocation in Switzerland, 2001–2020.

Health issue	Decision criteria	Case management and decision	Reference
Heart murmur (in absence of associated clinical signs)	- DS[1]: None; TH[2]: None - Previous data: suspected inherited cardiomyopathy	REPATRIATION	(Ryser-Degiorgis et al. 2018)
Parvovirus infection and excretion (faeces)[3]	- DS: None; TH: None - Not all Parvoviruses cause disease - Previously same situation in orphaned lynx: remained healthy, excretion stopped, was released and followed up	Retesting, negative in faeces (no excretion) and TRANSLOCATION	(Ryser-Degiorgis & Meli, unpubl.)
Cytauxzoon spp. infection[3]	- DS: None; TH: None - Retrospective analysis: many Swiss lynx infected, no known fatal cases in domestic cat in Europe at the time[4] (questionable parasite pathogenicity) - Widespread in healthy bobcats and Iberian lynx[5]	TRANSLOCATION	(Ryser-Degiorgis et al. 2010a)
Suspected FIV[6] infection	- DS: present and potentially associated with FIV infection - TH: None available - Deterioration of health status in quarantine - Retrospective analysis with reliable test (gold standard): Absence of positive lynx in source population confirmed	EUTHANASIA	(Ryser-Degiorgis et al. 2017)
Chlamydiosis	- DS: Yes, typical for infection; TH: Yes, available and feasible - No other known disease case in source population, infection status population unknown (neither previous data nor appropriate samples available)	TREATMENT, observation until total recovery and TRANSLOCATION (retesting at release and post-release observation by photo-trapping)	(Marti et al., 2019)
FeLV[7] infection	- DS: None; TH: None - Previous data: No infection in source population - Regressive infection, high antibody titre, no virus shedding	REPATRIATION and follow up (GPS collar, photo-trapping)	(Marti et al., unpubl.)

[1]DS: Disease signs; [2]TH Available therapy; [3]These experiences contributed to the classification of the corresponding infectious agents in the currently used risk category (see Table 2). [4]Since then, *Cytauxzoon* spp. has been shown to occur in both wild and domestic felids in Europe, with varying pathogenicity (from asymptomatic to fatal infections) and sometimes uncertain causal relationship between the infection and observed clinical signs (Nentwig et al. 2018, Panait et al. 2021). [5]Since then, *Cytauxzoon* spp. has also been detected in Eurasian lynx in Romania (Gallusová et al. 2016) and reported in European wildcats by multiple authors (Panait et al. 2021). [6]FIV: Feline Immunodeficiency Virus; [7]FeLV: Feline Leukaemia Virus.

of dead lynx) is a crucial point to evaluate the success of the project on a longer term and to determine the need for additional management measures.

Twenty years ago, when veterinary supervision was first implemented for lynx translocation projects in Switzerland, hardly any health issue was a limiting factor and infections seemed to be of minor importance, but over the past 10 years a range of microorganisms with pathogenic potential have been newly detected. The change from serological investigations to pathogen detection may have favoured this situation, however, pathogen detection partly followed the detection of associated clinical signs (Origgi et al. 2012, Ryser-Degiorgis et al. 2017, Marti et al. 2019). While both antigen and antibody detection are essential to study pathogen/disease dynamics in a population, only pathogen detection is relevant for decision-making in the framework of translocations (risk of excretion potentially leading to disease in stressed animals or resulting in contamination/transmission at the release site). On the same line, it is crucial to distinguish infection and exposure from disease and not to be misled by results of serosurveys (Munson et al. 2010).

The infections documented in lynx in Switzerland were most likely sporadic and related to the occurrence of the corresponding infectious agents in sympatric hosts such as foxes [sarcoptic mange (Ryser-Degiorgis et al. 2002b, Pisano et al. 2019); distemper (Origgi et al. 2012)] and possibly domestic cats and/or European wildcats *Felis sylvestris* [FIV (Ryser-Degiorgis et al. 2017); FeLV (Leutenegger et al. 1999, Meli et al. 2009, Geret et al. 2011, Hofmann-Lehmann et al. 2018); *Chlamydia felis* (Marti et al. 2019)]. Current information on Swiss stray and feral domestic cats is limited (Berger et al. 2015, Hofmann-Lehmann et al 2018; Novacco et al., 2019), but personal communications from clinical pathologists at the Clinical Laboratory of the University of Zurich support the occurrence of FeLV and suggest the presence also of other viruses such as FIV in feral and stray cats potentially sharing lynx habitat (B. Riond, pers. comm.). The regular record of heart anomalies possibly associated with a loss of genetic variability (Ryser-Degiorgis et al. 2018), have added concerns regarding the health status of the source populations and underlined the necessity of considering also non-infectious diseases in health risk assessments in the context of translocation projects.

Health surveillance and retrospective studies require access to a sample size sufficient for inference at population level (Ryser-Degiorgis 2013). In protected secretive species, the access to samples is typically difficult, as animals found dead and captured individuals represent the only possible sources of material. From a strategic viewpoint, three components of health surveillance appear to be particularly important: (1) long-term data and sample collection; (2) interdisciplinary collaboration and a combination of multiple diagnostic approaches (e.g., clinical and post-mortem examinations, laboratory tests, observations of disease signs by photo-trapping; examination of both marked animals and those found by chance; examination of diseased and of apparently healthy animals such as traffic kills, which can provide baseline data); (3) harmonization of data collection over time and among study areas to allow for comparisons. Last but not least, data need to be regularly compiled to improve protocols and procedures as appropriate. Overall, the aim is to carry out adaptive management based on scientific data (Fig. 5). For a pan-European conservation programme of Eurasian lynx, coordinated efforts are advisable. Among others, the harmonization of veterinary protocols and genetic investigations is desirable, as well as the exchange of information on detected health issues.

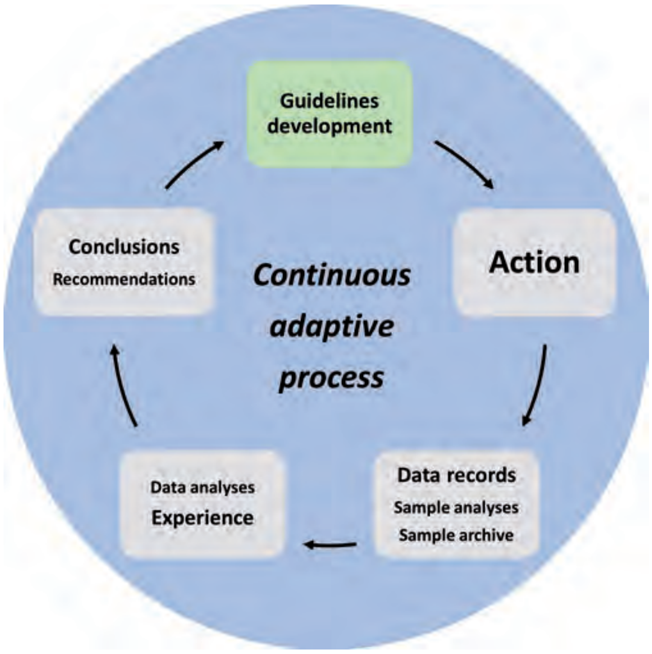

Fig. 7. Conservation of lynx populations, including but not limited to translocation procedures, requires adaptive management based on scientific data. This corresponds to a never ending learning process translating into continuous protocol adaptation.

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Supporting Online Material SOM Figures F1-F3 are available at www.catsg.org

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EAZA breeding programmes as sources for lynx reintroductions

The use of captive-born lynx for reintroduction programmes has been controversially discussed in the past, but projects such as the reintroduction in the Harz Mountains have demonstrated that zoo-born lynx can adapt to living in the wild. However, phylogenetic considerations require that the zoo-based population is known and that subspecies are bred in separate lines. EAZA has established ESBs for *Lynx lynx lynx* and for *Lynx lynx carpathicus*. In the future, these ESBs could also serve as source populations for reintroduction, provided that sensible protocols for breeding, husbandry, and training of lynx to be released to the wild are developed and followed.

The reintroduction projects in the Kampinos area (Poland; Böer et al. 1994, Blomquist et al. 1999) starting 1992 and in the Harz Mountains (Germany; Anders & Middelhoff 2021) starting in 2000 prompted an ongoing discussion on the suitability of zoo-born lynx for the creation of free-living populations (e.g. Wotschikowsky et al. 2001). The dispute was not only about the fitness of captive lynx for living in the wild, but also about the phylogenetic origin of the lynx in zoos. A preliminary inquiry by the European Association of Zoos and Aquaria (EAZA), an association of scientifically led zoos, revealed that even zoos of the association were not certain what "kind" of lynx that they owned, as no specific breeding management for Eurasian lynx in European zoos existed so far (Versteege 2005; 2009).

In 2002 the EAZA established a European studbook (ESB) for Eurasian lynx (Versteege 2009). Several subspecies are represented within the European zoo population. An assessment by the EAZA Felid Taxon Advisory Group (TAG) suggested focusing on breeding of Northern lynx *Lynx lynx lynx* and Carpathian lynx *Lynx lynx carpathicus* as the only sustainable populations (A. Sliwa, pers. comm.). Although the taxonomy of Eurasian lynx was long debated and sometimes differently interpreted, this is concurring with the most recent taxonomic classification and assignment to subspecies in Continental Europe by the IUCN Cat Specialist Group (Kitchener et al. 2017). These two ESBs are representing two prominent subspecies living in Europe, as no captive population of the Balkan lynx *Lynx lynx balcanicus* exists. All other subspecies, hybrids and specimens of unknown origin living in EAZA zoos have been pooled in a phase-out-population, currently still at 120 individuals (Lengger 2020) to provide space for these two subspecies. Since then, Carpathian lynx numbers have tripled from 50 individuals in 2002 to 154 specimens kept in 56 institutions in 2019 (Fig. 1, 2; Lengger 2020). The Northern lynx ESB population presently stands at 184 (Fig. 3). After a decade of population growth, EAZA zoos have reached their maximum carrying capacities, which required a reduction of breeding recommendations by the studbook in recent years (Lengger 2020). The goal of the zoo populations is also to include as much of the gene pool as possible. Presently under-represented lineages will be furthered and new founders may enter the population in the future. However, some of the founders of the ESB population with unknown parentage have been classified on morphological traits only and could hence be crossbreeds of several subspecies. A molecular genetics study could help to clarify this risk (Versteege et al. 2017) and is now initiated.

In the past, reintroductions with captive bred lynx (Kampinos National Park, Poland, 1992–1999, Harz Mts., Germany, 2000–2007) have been conducted with varying success (Breitenmoser & Breitenmoser-Würsten 2008, Anders & Middelhoff 2021). The Harz project has demonstrated that lynx born and/or grown up in captivity can be used for reintroduction. However, anecdotal observations suggest that not all animals can adapt to living in the wild. We assume that, besides individual differences, breeding, husbandry, and training of captive-born lynx are crucial for their successful releasing, and that these aspects hence require specific consideration and protocols.

Beside reintroducing populations to former distribution areas, the genetic restoration of existing wild lynx populations could be a future scenario for the use of captive animals (Bonn Lynx Expert Group 2021). Therefore a full genetic evaluation of the current zoo population is needed, as in the past some individuals of unknown parentage were assumed to be of pure subspecies origin based on phenotypic traits (Versteege 2009). Besides their phylogenetic origin, the genetic variability (e.g. heterogeneity) of the zoo populations compared to the wild source populations needs to be known and considered.

We are convinced that zoos could play a significant role in the efforts to restore or remedy lynx populations in Europe. Zoo-born lynx would have, compared to wild-caught specimens, some considerable advantages,

Fig. 1. Carpathian lynx male in Dortmund Zoo (Photo A. Sliwa).

as their individual genetic background and their health status can be established long before the translocation. Although husbandry guidelines for Eurasian lynx in EAZA zoos exist (Krelecamp 2004) these have to be specified to a much greater degree for the specific purpose of providing lynxes for reintroduction and restocking. Detailed protocols for breeding, husbandry, training and rewilding such lynx will have to be jointly developed by lynx experts, the EAZA Felid TAG and ESB, and relevant IUCN SSC institutions (e.g. Cat Specialist Group, Conservation Translocation Specialist Group (formerly Reintroduction SG), and LCIE). These protocols must then be adhered to, and each zoo/lynx holding facility potentially participating in such a programme would have to fulfil a strict list of requirements, which will also include the veterinary and behavioural testing of lynx to be released. The Carpathian lynx ESB could soon be ready to provide animals for breeding for release in the respective range (Fig 1 in Bonn Lynx Expert Group 2021). With the Northern lynx ESB, there is however an important phylogenetic question to be answered: Are the Scandinavian and Fenno-Baltic lynx phylogenetically close enough to be considered an ESU? Until this question is answered, we recommend using only wild lynx from the Baltic population or captive-bred lynx demonstrated to belong to the Baltic or the Karelian populations for any reintroduction or reinforcement in the region of the Baltic lowland lynx (Fig. 2 in Bonn Lynx Expert Group 2021).

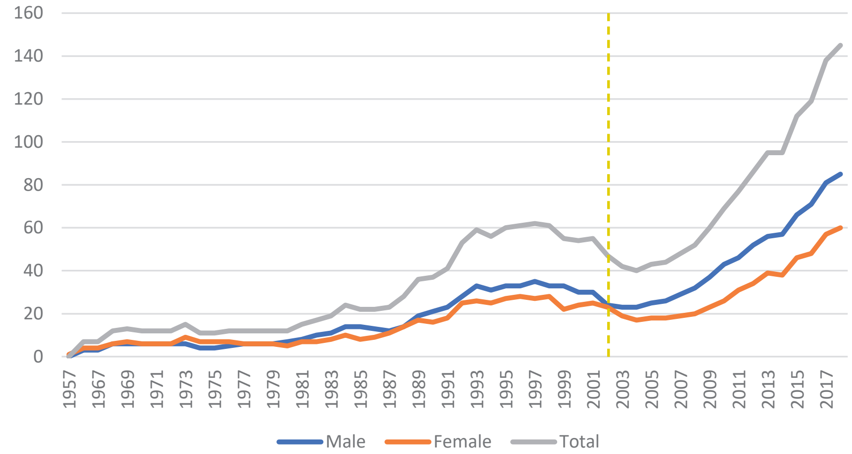

Fig. 2. Development of the EAZA ESB population of *Lynx lynx carpathicus*. Yellow dashed line indicates start of studbook in 2002.

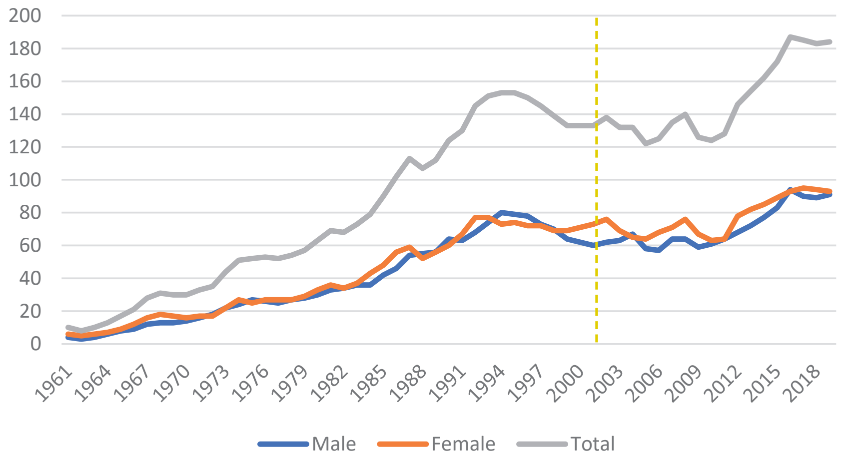

Fig. 3. Development of the EAZA ESB population of *Lynx lynx lynx*. Yellow dashed line indicates start of studbook in 2002.

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BONN LYNX EXPERT GROUP[1]

Recommendations for the conservation of the Eurasian lynx in Western and Central Europe

Conclusions from the workshop of the "Bonn Lynx Expert Group" in Bonn, Germany, 16–19 June 2019

The first assessment of the Eurasian lynx *Lynx lynx* across Europe was initiated by IUCN and WWF International in 1962, when the two organisations asked the Czech zoologist Josef Kratochvíl to review the status of the species across the continent (Kratochvíl et al. 1968a, b). A wider audience however became only aware of the fate of this elusive species when in the early 1970s, the reintroduction programmes started in Western and Central Europe (overview in Breitenmoser & Breitenmoser-Würsten 2008). In 1990, the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) of the Council of Europe, commissioned a review of the status and the conservation needs of the lynx in Europe (Breitenmoser & Breitenmoser-Würsten 1990). Since then, a number of pan-European or transboundary conservation assessments and strategies were produced:

- Action Plan for the Conservation of Eurasian lynx (*Lynx lynx*) in Europe (Breitenmoser et al. 2000);
- The Pan-Alpine Conservation Strategy for the Lynx (Molinari-Jobin et al. 2003);
- Status and conservation of the Eurasian lynx (*Lynx lynx*) in Europe in 2001 (von Arx et al. 2004)
- Conservation Strategy and National Action Plans for the conservation of the Critically Endangered Balkan Lynx (Council of Europe 2011);
- Key actions for Large Carnivore populations in Europe (Boitani et al. 2015);
- Lynx in the Alps: Recommendations for an internationally coordinated management (Schnidrig et al. 2016);
- *Lynx lynx*: European regional assessment in the IUCN Red List of Threatened Species (von Arx 2018).
-

Although the situation of the lynx has improved since the population minimum in the middle of the 20th century, the above listed conservation plans have revealed that there is a considerable need for more focused conservation efforts in all autochthonous and reintroduced populations in Western and Central Europe. The past years have seen a marked increase of lynx projects in Continental Europe (see individual chapters of the proceedings of the Bonn conference in this Special Issue). This development is most welcome, but it calls for more cooperation and a common understanding and approach on the conservation and management of the lynx in the Western and Central European countries. Lynx as apex predators are rare animals, and their distribution is so far restricted to forested areas. Except for the major mountain ranges such as the Alps, the Carpathians or the Dinaric Range, none of the Western and Central European secondary mountain ranges or low-land forests could host a (genetically) viable lynx population in the long run as long as they are isolated. Therefore, the recovery and maintenance of demographically and genetically viable lynx populations entail a metapopulation-approach and transboundary cooperation. Activities such as "assisted dispersal" (translocations), reintroductions or genetic remedy (reinforcement) furthermore require standards and common protocols, because activities in one population in one country will ultimately affect those of neighbouring countries.

At the conference in Bonn, 16–19 June 2019, a group of 53 experts from across Europe gathered to review the situation of the Eurasian lynx in Western and Central Europe, to enunciate recommendations for the conservation and management of lynx, and to stipulate a number of standards and protocols.

The following recommendations should provide practical guidance for ongoing and future conservation projects in Western and Central Europe and for the cooperation between projects and countries. They are based on the best presently available information and science and are meant to set the standard for lynx conservation projects for the years to come. They are addressed to scientists as well as conservation practitioners, but also to decision makers in governmental institutions and to potential donors of lynx conservation projects.

Strategic preamble

The Eurasian lynx is protected under the Bern Convention (Appendix III with the exception of the Balkan lynx *Lynx lynx balcanicus*, which is listed under Appendix II) and the EU Habitats Directive (Annexes II and IV, except for Estonia, Finland and Latvia, where it has an exception from Annex II; von Arx 2018). According to the Convention on Biological Diversity, "the fundamental requirement for the conservation of biological diversity is the in situ conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings". The lynx is an apex predator of European forested habitats, preying mainly on roe deer, but also on other small ungulates and a number of medium-sized mammals. The presence of lynx contributes to the ecological functionality of these ecosystems and preserves their evolutionary potential. Threats to lynx have been reviewed in all above-mentioned documents. The latest population-based review was done for the period 2012–2016 by von Arx (2018) in the frame of the IUCN Red List assessment for Lynx lynx in Europe (see "Threats in Detail"). Threats in Continental Europe are mainly anthropogenic, either human-induced mortality or intrinsic threats due to the limited size and isolation of the population in the modern cultural landscape. But all these threats can be mitigated though adequate measures.

The strategies and action plans for the Eurasian lynx in Europe listed above have all expressed the intention to maintain or recover viable lynx populations within the species' historic range wherever the ecological and anthropogenic environments allow it.

Strategic framework

The participants at the Bonn workshop have reviewed the goals and objectives of the above-mentioned documents and synthesised the following strategic framework for the long-term conservation of the Eurasian lynx in Western and Central Europe.

Goal:
Maintain and restore, in coexistence with people, viable populations and metapopulations of Eurasian lynx in a favourable conservation status as an integral part of ecosystems and landscapes across Continental Europe.

The general Goal will be reached by striving for the following six Objectives:

- **Objective 1.** To conserve all autochthonous populations, to enable their natural spread and recovery and to safeguard distinct evolutionary significant units (ESUs) of the Eurasian lynx in Continental Europe, and to take all measures needed to prevent local extinction.
- **Objective 2.** To conserve all reintroduced populations of Eurasian lynx and to promote in accordance with IUCN guidelines further reintroductions in patches of suitable habitat apt for hosting viable populations or relevant subpopulations or "stepping stones" contributing to the functioning of a larger metapopulation.
- **Objective 3.** To foster the natural or assisted connectivity between populations of the same phylogenetic units (e.g. subspecies[1] or ESUs) in order to secure the long-term maintenance of large viable metapopulations.
- **Objective 4.** To develop and implement management measures addressing the interactions concerning lynx in the cultural multi-purpose landscapes of Europe (e.g. with regard to forestry or hunting).
- **Objective 5.** To generate and provide objective information through monitoring and research to continuously observe the conservation status of each population and to propose the appropriate conservation measures.
- **Objective 6.** To reduce human-induced mortality of lynx, esp. by illegal killing and vehicle collisions.

These Objectives will, among others, be achieved by accomplishing the following seven concrete Results:

- **Result 1.** Agreement on "evolutionary significant units[1]" of Eurasian lynx in Continental Europe, their geographic delineation and the use of ESUs/subspecies for further translocations.
- **Result 2.** A preliminary spatial metapopulation concept for Continental Europe to guide the improvement of functional connectivity between now isolated subpopulations[2] and implement respective practical measures.
- **Result 3.** Recommendations on common approaches shared protocols for surveys and monitoring, and pooling data and information from surveys of lynx populations (including demographic, health and genetic status).
- **Result 4.** Recommendations on genetic surveillance, management and remedy of inbred populations: why, when, how?
- **Result 5.** Recommendations on the use of suited source populations for reintroductions, reinforcements or "assisted dispersal" (metapopulation management).
- **Result 6.** Recommendations on best-practice protocols for health considerations and the practical execution of translocations, including quarantine and (transboundary) transport.
- **Result 7.** Outlook on the long-term cooperation for the conservation of the lynx in Western and Central Europe: (1) engagement with international conventions and national conservation institutions, (2) involvement of stakeholders at international level (and subsequently at national and local level), (3) need for developing common transboundary management approaches, and (4) need for strengthened cooperation/coordination at regional or metapopulation level.

Recommendations

The following Recommendations are the joint work of the participants of the Bonn Lynx Expert Group (Appendix I). The Recommendations were prepared in Working Groups, discussed in the Plenary, formulated by a drafting group and finally adopted by all participants.

1. Delineation of phylogenetic lines of lynx in Continental Europe

Three subspecies of *Lynx lynx* were described for Europe (Kitchener et al. 2017): the Northern lynx *L. l. lynx* (Linnaeus, 1758), the Carpathian lynx *L. l. carpathicus* (Heptner, 1972), and the Balkan lynx *L. l. balcanicus* (Bureš, 1941). The phylogenetic subdivision of the species is still under discussion. For instance, the Scandinavian population (von Arx et al. 2021) is genetically distinct from the Karelian and the Baltic populations (e.g. Hellborg et al. 2002), or *L. l. balcanicus* might be part of *L. l. dinniki* (the Caucasian lynx; Kitchener et al. 2017). Nevertheless, the present state of research indicates the presence of three extant phylogenetic lines in Continental Europe, which we recommend to treat as distinct "evolutionary significant units" (ESU): the Baltic, the Carpathian and the Balkan ESU.
The most threatened of these ESUs is the Balkan lynx, which is considered to be Critically Endangered according to the IUCN Red List of Threatened Species (Melovski et al. 2015). The Balkan lynx is subject of an ongoing recovery programme based on a conservation strategy (Council of Europe 2011); its conservation is hence not further elaborated in these recommendations. The general approach is to strengthen the remnant population in its present distribution area and help it expanding across the assumed historic range on the southern Balkan Peninsula. A viable Balkan population will be able to resist the competition with immigrating *L. l. carpathicus* from either the autochthonous Carpathian population or the reintroduced Dinaric population, as it has done for thousands of years in the past. An alternative conservation strategy would have to be developed if further monitoring reveals that the extremely small Balkan lynx population is (genetically) no longer viable.
Similar to the Balkan lynx, the conservation of the autochthonous populations of the Carpathian and Baltic lynx must have high priority. Both populations stretch over several countries (von Arx et al. 2021; Fig. 1) and would highly profit from common population-level conservation and management plans jointly developed by the countries sharing these populations and subsequently implemented through national action plans. The Baltic population is part of the large north-eastern European lynx (e.g. the Karelian) population, but it is severely fragmented in its south-western area. The Carpathian population is apparently divided into a northern and a southern part,

[1] For the Eurasian lynx, a number of distinct subspecies have generally been accepted, although not all of them are based on sufficient scientific evidence (Kitchener et al. 2017). Wherever sensible, we consider subspecies to be the ESUs.
[2] A subpopulation is a subset of a larger metapopulation; several subpopulations together form a metapopulation. Subpopulations are separated by barriers or less suited habitat, which are however permeable enough to allow a migration of individuals sufficient to maintain the demographic and genetic viability of the subpopulations.

Fig. 1. Distribution of *Lynx lynx* in Continental Europe 2012–2016 according to a LCIE survey (von Arx 2018). The autochthonous populations (green circles) represent three different phylogenetic lines, which should be conserved as such. The dashed lines (dark red) represent the proposed delineation of the ESU's distribution range for recovery and reintroduction projects, respectively.

as the lynx in the Ukrainian Carpathian Mountains seems to be practically extinct (Fig. 1).

For the reintroduction of lynx in Western and Central Europe, which started almost 50 years ago, Carpathian lynx were generally used, with the exception of the reintroductions in the Kampinos National Park (Poland) and the Harz Mountains (Germany), where generic lynx from zoos were released (Breitenmoser & Breitenmoser-Würsten 2008). Today 87.5% of the Harz animals show haplotype 4 (Mueller et al. 2020), which is the only one found in the Carpathian lynx population. Although this haplotype is not exclusive, as it also occurs in the Baltic population, we can assume that most of the haplotypes 4 came from the Carpathian population (T. Reiners, pers. comm.).

To use Carpathian lynx in the early reintroductions in the 1970/80s was an arbitrary decision based on the geographic proximity and the habitat similarities of the Carpathian Mountains. Today, we know that the lynx historically living e.g. in the Alps were genetically not identical to the Carpathian lynx (Gugolz et al. 2008), but the lynx historically inhabiting these ranges are lost forever, so it was justifiable to use the nearest ecotype. The participants of a workshop on the genetic status and conservation management of reintroduced lynx populations in 2011 recommended continuing using *L. l. carpathicus* for the entire region where this phylogenetic line was used before (Breitenmoser 2011). So we distinguish three "lynx regions" in Continental Europe (Fig. 1): (1) the area of the Balkan lynx in the south-east, including the southern part of the Dinaric Range (extant area), and the Balkan and Rhodope Mountains as historic and potential expansion range. (2) The region between the central Dinaric Range and the southern rim of the Carpathians north to the Harz Mountains as extant or future distribution range of *L. l. carpathicus*. This would include large ranges such as the Alps, but also all secondary mountain chains in Western and Central Europe where Carpathian lynx have been reintroduced since the 1970s. (3) The lowland of the north-Continental plain should be considered the extant or future range of the Baltic lynx.

Recommendations:

- Distinguish three areas of distinct phylogenetic lines in Continental Europe (Fig. 1): *L. l. balcanicus* in the south-east (southern Dinarides or Hellenides, Balkan Range and Rhodope Mountains); *L. l. carpathicus* from the southern Carpathians and the central Dinaric Range north to the Harz Mountains, including the Alps and all secondary mountain ranges of Western and Central Europe; (3) the "north-eastern European lowland lynx" in the plains of north-Continental Europe north-east to the Baltic countries (see 3.5 for recommendations on source populations).
- Dispersal across the delineation line of the ESUs (Fig. 1) is a natural process that was occurring for thousands of years. It should neither be prevented nor furthered, but weak indigenous populations such as the Balkan lynx should be strengthened through sensible conservation measures.
- Within the designated distribution range of an ESU, the genetic diversity of each population should be optimised, monitored and maintained high (see 3.2 and 3.4).

2. Metapopulations of lynx in Continental Europe and connectivity

Both, habitat (forest cover and in large areas tree diversity) and prey base (e.g. roe deer) have considerably improved in Western and Central Europe since the historic lynx populations went extinct in the 19th century (Breitenmoser & Breitenmoser-Würsten 2008). Besides the large ranges such as the Carpathians, Alps or Dinaric Range, many of the secondary mountain ranges of Continental Europe nowadays provide well suited habitat for lynx, but their spatial extent may not be sufficient to host a genetically viable population. In the long term, the ultimate distribution range of each of the ESUs should be considered and managed as one genetic metapopulation. Some of the connections between subpopulations are obvious and have been demonstrated (e.g. Herdtfelder et al. 2021); some are speculative and anticipated only (as presented in Fig. 2 for the Carpathian lynx). Some populations are separated by distance and suboptimal habitat, others are close together, but separated by severe barriers like large rivers, agglomerations or major traffic axes. Lynx show a sex-biased dispersal: Male lynx go further and pass considerable barriers such as the main ridge of the Alps or the Rhine River. The potential of individual lynx to move across the cultivated and human-dominated landscapes of Western and Central Europe is considerable, but demonstrated cases of migration between populations with successful integration (reproduction) of the immigrant, are so far very rare. Success of migration depends on the distance and corridor quality between neighbouring populations, but also on the status of the source and target population. Connectivity and exchange of individuals can be predicted by means of models (Premier et al. 2021), but its effect on genetic diversity will ultimately have to be evaluated by means of genetic monitoring (see 3.4).

Several large "potential populations" or "metapopulations" have been proposed: The "Alpine population" (A in Fig. 2), has been considered as a potential population in the frame of the SCALP (Status and Conservation of the Alpine Lynx Population) concept (e.g. Molinari-Jobin et al. 2003, Schnidrig et al. 2016, Molinari-Jobin et al. 2021). The secondary mountain ranges of the Jura, the Vosges-Palatinate Forest, and the Black Forest are proposed as the "upper Rhine metapopulation" (B in Fig. 2; Krebühl et al. 2021). The well-forested mountain ranges surrounding the Czech Republic, with the Bavarian Forest in the west and the Carpathians in the east were proposed as potential metapopulation (C in Fig. 2; called "CELTIC" metapopulation by Wölfl et al. 2001; see also Wölfl et al. 2021). Last but not least, the Carpathian population (D in Fig. 2), always considered a stronghold of lynx in Central Europe, is today severely fragmented and may be functionally a metapopulation. Although the metapopulation concept presented here is not fully consistent and may have to be adapted in the future, it is a useful concept to plan the merging of fragmented populations or isolated occurrences. Connectivity between neighbouring populations must be maintained or restored through habitat amelioration, the creation of corridors, the mitigation of barriers such as traffic axes wherever feasible, or targeted stepping-stone releases (Molinari et al. 2021).

Recommendations:

- Each transboundary population or designated metapopulation should be cooperatively monitored and transboundary conservation and management plans should be developed based on the principles proposed by Linnell et al. (2008). A common conservation strategy is especially recommended for the autochthonous Carpathians and Baltic populations.
- The knowledge on lynx movements between populations must be refined. This includes common monitoring of the population (genetic status) and movement of individuals (dispersal of both sexes), but also understanding of habitat, corridors, and obstacles to lynx movements.

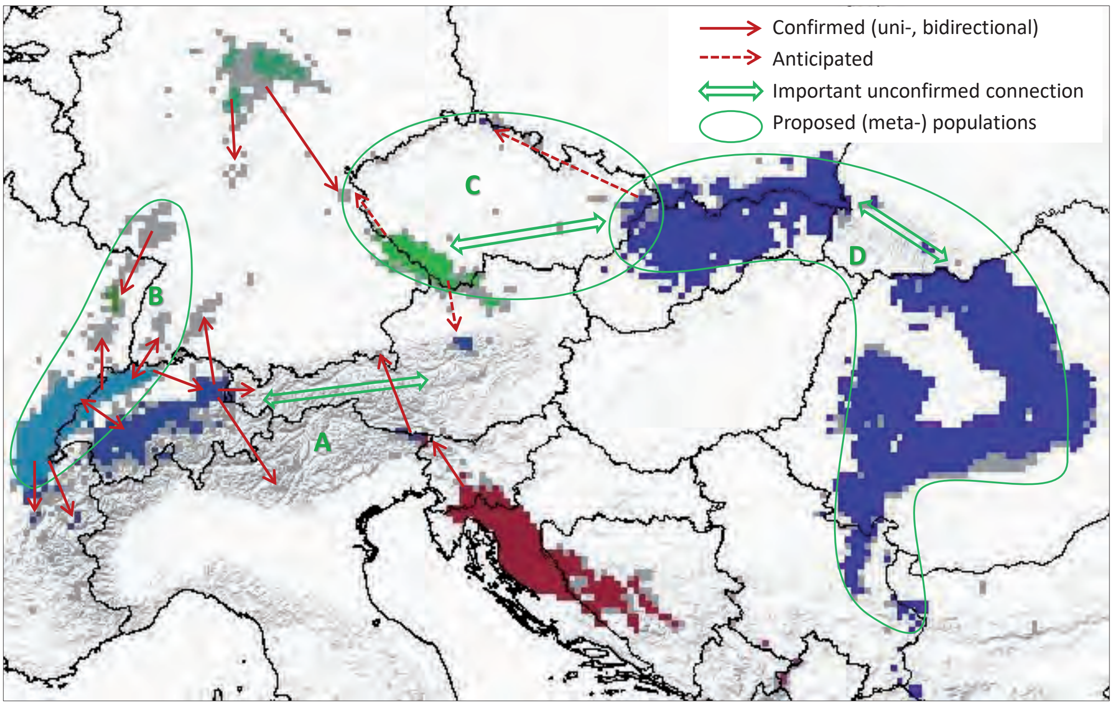

Fig.2. Distribution of the Carpathian lynx *L. l. carpathicus* in Continental Europe 2012–2016 (colours = populations), confirmed (radio-telemetry, camera trapping, or genetics), or anticipated movements of lynx between populations (arrows), unconfirmed, but potentially important connections, and proposed (meta-) populations (polygons A–D, see text) to be conserved and managed as larger units.

- Wherever considered insufficient (e.g. based on genetic monitoring), functional connectivity should be improved (e.g. restoring corridors, green bridges, mitigation of human-induced mortality, etc.). Where the enhancement of natural migration is not possible or too expensive, assisted dispersal by means of translocations must be considered. Local populations should not be allowed to drop below functional (demographic) viability.

3. Concepts for monitoring of the conservation status of lynx populations

The pan-European review of the conservation status of the European lynx populations was coordinated by the Large Carnivore Initiative for Europe (LCIE). A comprehensive assessment is preformed every six years based on the IUCN Red List assessment procedures (von Arx 2018; von Arx et al. 2021). The pan-European assessment is a compilation of population and country oriented information ranging from expert opinion to robust quantitative estimations of abundance. A number of countries have adopted specific protocols for the monitoring of lynx (e.g. Breitenmoser et al. 2006; Reinhardt et al. 2015; Gimenez et al. 2019; Zimmermann 2019), and for several populations, a transboundary coordinated monitoring scheme or at least a procedure for the common interpretation and release of monitoring reports have been established (e.g. the Norwegian-Swedish Instructions for lynx monitoring; Alps, Molinari-Jobin et al. 2021; Bohemian-Bavarian-Austrian population, Wölfl et al. 2021). Monitoring the conservation status of a species includes information on distribution, population size, population dynamics (demography), health, genetic status, threats and conflicts. The following recommendations address the (technical) monitoring of the ecological and biological parameters of lynx, although we are aware that monitoring of conflicts with human activities (hunting, livestock breeding) and peoples' attitudes are as important for the successful implementation of conservation programmes.

Distribution is generally the first aim of repeated monitoring. At a European scale, distribution is presented by means of the 10 x 10 km EEA (European Environment Agency) reference grid, with some specification per cell, such as permanent (with/without reproduction), sporadic or uncertain presence (Kaczensky 2018) based on reported records per country differentiated according to the SCALP Criteria from the standardised monitoring for the Alps (Molinari-Jobin et al. 2012). The result is a naïve occupancy map, mostly based on chance and opportunistic observations, for certain populations or countries including information on reproduction. For some countries, distribution information is however still based on expert opinion or a rather randomly collected set of observations.

Population size (population indices, minimum count, robust capture-recapture estimates) in Continental Europe bases today mainly on camera trapping (different to more northern countries, snow tracking is nowhere systematically used) and partly on radio-telemetry (mostly combined with research projects). The most reliable abundance or density estimations are achieved with capture-recapture analyses of camera-trapping data (e.g. Zimmermann & Foresti 2016; Gimenez et al. 2019). Camera-trapping sessions in reference areas should be repeated about every two to three years to gain a sufficient resolution of population trends and to get reliable demographic parameter estimates (e.g. survival, recruitment).

Demographic data (natality, mortality, age structure and sex ratio) are important and should at least be systematically collected as chance observations throughout the distribution range. Further demographical parameters such as growth rate, survival, or recruitment can be estimated by means of capture-recapture models.

Population trend describes temporal change of parameters such as distribution, population indices, abundance and density. Monitoring and interpreting trend information is fundamental to draw the right conclusion with regard to conservation or management interventions.

Health monitoring is of growing importance especially for the small populations in Continental Europe, as health issues may be linked to population size and genetic status and may become more important with climate change (emerging pathogens). Furthermore, a health screening following agreed veterinary protocols are required for any translocation of lynx between populations or countries. Health concerns include harmonised screening of the populations (e.g. protocol for necropsy), handling of live caught animals (anaesthesia, health check-up) and veterinary requirements for translocations (transport, quarantine, health reporting; Ryser-Degiorgis et al. 2021). Veterinary protocols should be coordinated with the genetic monitoring (see below).

Recommendations:

- The compilation, analysis, interpretation and presentation of distribution records (systematically compiled, georeferenced, dated and categorised chance observations) needs to be standardised for all countries sharing a population, and harmonised distribution maps for the entire population should be updated regularly
- Occupancy models should be computed besides presenting the naïve occupancy to compensate for incomplete detection (e.g. Molinari-Jobin et al. 2018).
- A standardised protocol for camera-trapping for abundance/density estimations for Western and Central Europe needs to be developed (reference area, size and camera-trap spacing, duration, season, data analysis and interpretation).
- A series of standardised veterinary and health protocols (capture and anaesthesia, health screening, necropsy, quarantine, transport, reporting) need to be developed (or adapted/translated where they already exist), made available and regularly reviewed and updated (see also Online Supporting Material to this issue).
- To tackle the above-mentioned tasks and to develop/harmonise the proposed protocols, permanent expert working groups on (1) monitoring and (2) health issues should be established.

4. Principles for the genetic monitoring and management of lynx populations

Genetic monitoring is important for all small, reintroduced, isolated, and fragmented populations, and for those that went through a serious historic bottleneck. In other words: for all European lynx populations. The reintroduced populations will not be (genetically) viable in the foreseeable future, so they need short- to long-term genetic management. All reintroduced lynx populations in Central and Western Europe with exception of those in Poland are considered part of the Carpathian lynx ESU.

Small and isolated populations should be genetically managed to minimise loss of genetic diversity (heterozygosity, allelic richness) and to keep the inbreeding coefficient F_{IT} below 0.15. If the inbreeding coefficient exceeds 0.25 (equivalent to full sibling mating) immediate action is needed to restore the genetic variability of the populations and decrease the inbreeding coefficient. Gene flow should be established within a local metapopulation to reach these goals. If this is not possible or not sufficient through natural migration, assisted gene flow (assisted dispersal) has to be implemented. If local metapopulation dynamics (within an extant, but fragmented population or between neighbouring reintroduced populations) is functioning either through natural gene flow or assisted dispersal, the effective population size of the population/metapopulation (Fig. 2) should not drop below an effective population size of 100 mature individuals as recently proposed by Frankham et al. (2014). Consequently, releasing related animals in newly founded or very small population nuclei should be avoided. Related animals and animals from inbred populations should not count fully, but e.g. 2 siblings as 1.75. Genotyping of each animal to be released is mandatory.

The sampling of material for genetic analyses needs to be included in monitoring protocols: Opportunistic sampling (e.g. from dead or captured lynx) has to be permanently implemented across the range. If a sample-size goal of 30 animals per generation (5 years) per population is not reached, sampling needs to be intensified. A common panel of 15 microsatellites should be used across the range by all laboratories involved in genetic monitoring of lynx. Calibration samples need to be exchanged between participating laboratories and a calibration table should be shared. New marker systems should be tested as they become available.

Recommendations:

- Genetic monitoring needs to be established where it does not already exist and must become mandatory for all lynx populations in Continental Europe. This includes the tracking of genetic diversity and inbreeding over time, allowing assessing the effective population size (Ne) and the detection of gene flow between neighbouring populations.
- To establish an assisted metapopulation management, a system for assessing and exchanging animals (e.g. orphaned lynx) between reintroduced and other genetically deprived populations/subpopulations needs to be developed.
- A permanent lynx genetics working group including experts from the laboratories involved in genetic monitoring and research should be established. This group should develop a more detailed protocol for genetic monitoring and conservation (genetic remedy of inbred populations, long-term genetic management of the metapopulations). Regular exchange of information between participating laboratories and with the in situ projects needs to be secured. Any new laboratory starting to work in lynx genetics is encouraged to join the working group.

5. Source populations for reintroductions or reinforcement

Reintroduction projects, reinforcement (including stepping-stone nuclei; Molinari et al. 2021), genetic remedy of inbred populations and continued genetic management (assisted dispersal/translocation) need suited lynx to be translocated and released. Until recently, the dominating source was the autochthonous population of Slovakia, which however has some conservation concerns itself (Kubala et al. 2021). The LIFE Lynx Project aiming at mitigating the inbreeding of the Dinaric population has now established Romania as a source for providing lynx (Fležar et al. 2021). However, although the autochthonous populations will remain an important source for reintroductions and reinforcements, capturing and translocating wild animals is increasingly complicated because of partly conflicting welfare, health and genetic considerations (see 3.6).

Alternative sources are the Eurasian lynx breeding programmes of the European Association of Zoos and Aquariums (EAZA). The EAZA today maintains two European Studbooks (ESB) for Eurasian lynx, one for *L. l. lynx* and another one for *L. l. carpathicus* (Lengger et al. 2021). After the genetic status and relatedness of the ESBs have been tested, these breeding programmes will be ready to provide animals for releases – provided that lynx designated for being released are bred, managed, trained and tested according to a rigorous protocol. The Carpathian lynx ESB is basically ready to provide animals (Lengger et al. 2021) for being released in the respective range (Fig. 1). With the Northern lynx ESB, there is however an important phylogenetic question to be answered: Are the Scandinavian and Fenno-Baltic lynx phylogenetically close enough to be considered an ESU? Until this question is answered, we recommend using only wild lynx from the Baltic population or captive-bred lynx demonstrated to belong to the Baltic or the Karelian populations for any reintroduction or reinforcement in the region of the Baltic lowland lynx (Fig. 1).

A third "source" are orphaned lynx, which come up almost yearly in any of the populations. Such lynx often show up in human vicinity and then taken into an enclosure in late fall and may be released in spring when they are about one year old, hence in their dispersal age. Provided that they are physically and mentally healthy and genetically fit (e.g. come from a population that is recommended as a source for translocation), such subadult animals are ideally suited to be translocated. Experience with regard to the survival of rehabilitated orphans is mixed. However, they do not seem to have a lower survival rate compared to naturally dispersing yearlings. A pan-European compilation and review is presently under way to review the survival of rehabilitated orphans and their potential to be used for reintroduction projects or genetic remedy (A. Molinari-Jobin, pers. comm.).

Recommendations:

- Sources for reintroductions and reinforcement (genetic remedy) in the designated distribution area of the Carpathian lynx (Fig. 2) are (1) the autochthonous population in Slovakia and Romania, (2) lynx (including orphans) taken from any population that meets the genetic requirements (see 3.4), and (3) properly managed specimens from the EAZA Carpathian lynx ESB.
- Sources for the reintroduction in the "Baltic lowland lynx" area (Fig. 2) are suited wild animals form the Baltic or Karelian populations or specimens from the EAZA Northern lynx ESB if it is demonstrated that they belong to the Fenno-Baltic line.
- If animals are taken from free-ranging populations, the removing of individuals must not be detrimental to the source population. This must be demonstrated by an adequate monitoring/assessment before and after the captures.
- Specific protocols must be developed for (1) breeding, husbandry, training and assessment of zoo-born lynx designated to be released, and (2) for the rehabilitation, husbandry, training (if needed) and evaluation of orphaned lynx to be released. These protocols must be jointly developed by lynx experts, the EAZA Felid TAG and ESB, and relevant IUCN SSC institutions (e.g. Cat Specialist Group, Conservation Translocation Specialist Group (formerly Reintroduction SG), and LCIE).

6. Protocols for translocation of lynx

Reintroduction and reinforcement including genetic management require the translocation of lynx from its place of origin to the release site. This process requires a number of legal obligations and practical precautions with regard to the safety of the animal, the people, and the ecosystem at the capture and release sites. General guidance for the planning of translocations is provided e.g. by the IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN/SSC 2013) or the Guidelines for the management of confiscated, live organisms (IUCN 2019). Wild-to-wild translocations generally include the following practical components:

Capture: Choice of adequate trapping system, surveillance system, competent handling of the animal including anaesthesia, examination, and decision on the suitability of the individual.

Quarantine: Preparation of quarantine station (to minimise risks of injuries and stress and to meet legal requirements where required), examinations and assessments during the quarantine time (diseases, genetics, signs of stress), duration (as short as possible, as long as needed; duration of the quarantine often requires a compromise between welfare and veterinary requirements), re-capture and preparation for transport/release (e.g. collaring).

Transport: Appropriate transport box and vehicle (both need to be well ventilated), timing (e.g. if border formalities are needed), transport team (driver(s), veterinary attendant). For long journeys, animal care-takers and transport vehicles have to be certified by the EU TRACES (Trade Control and Expert System) system.

Many of these considerations concern the translocation of zoo-born lynx, too, but zoo born lynx have the advantage that the suited individual can be selected in advance and that its genetic constellation, its behaviour, and to a certain extent its health status is known before the capture. Recent experiences with translocation of lynx are available from the reintroduction projects in north-eastern Switzerland (taken into account in Breitenmoser et al. 2014), in the Palatinate Forest (Idelberger et al. 2021) and reinforcement project in the northern Dinaric Range (Fležar et al. 2021). The joint experiences from these projects allow producing specific and detailed guidelines and protocols for the translocation of Eurasian lynx.

Recommendation:

- A working group should be established to draft detailed protocols for capturing, treating/examining, quarantining and transporting of Eurasian lynx for translocations (see 3.).

7. Cooperation in lynx conservation in Europe

The recovery and long-term maintenance of viable metapopulations of Eurasian lynx in Europe requires the involvement of many institutions and interest groups. The Bonn symposium and workshop was a meeting of wildlife researchers and conservationists. The plenary discussion revealed that there is a demand for exchange beyond scientific publications and a need for a more coordinated and institutional cooperation beyond the "Bonn expert group". The following topics were addressed:

Sharing of information: For the continuous assessment and conservation of the European lynx metapopulations, data on the status of the populations (abundance, trend, demography, genetics, and health) and ecological information need to be shared. Development of sensible conservation programmes furthermore requires information on (1) laws, policies, strategies and action plans, (2) threats to the lynx and coexistence with people, (3) economic aspects (prevention and compensation of depredation, impact on hunting, ecotourism), and (4) communication and awareness. For the practical implementation of conservation and management measures, information should be shared on (1) approaches (concepts, tools, protocols) and experiences (results), (2) upcoming research and conservation projects, and (3) lessons learnt and best practices. This combined experience should be compiled into recommendations and guidelines, which are to be regularly updated.

Scientific and popular publications are the basic way of sharing information, but they should be supplemented through (1) regular multinational and interdisciplinary meetings, (2) information and data sharing platforms (e.g. EUROLYNX; Heurich et al. 2021), (3) targeted information to over-arching conservation institutions and authorities in charge (e.g. IUCN SSC groups, conventions and national governmental institutions, interest groups at international, national and local level).

Outreach to other institutions and interest groups: The group of experts, which met in Bonn, needs to engage more with international conventions, national governments and stakeholders groups, and needs to advance the development of transboundary conservation strategies or management plans and strengthen the cooperation at regional and metapopulation level.

International conventions to be involved in long-term lynx conservation are the Bern Convention (Council of Europe; see 4. Concluding remarks), the EU Commission (Habitats Directive), the Alpine Convention's Platform Wildlife and Society, the Carpathian Convention, and IUCN SSC and its specialist groups. These bodies should regularly be informed and invited to participate in further meetings on lynx conservation in Europe.

National authorities concerned with the conservation and management of lynx should be continuously informed "bottom up" through project holders and wildlife experts, by the "Bonn expert group" as needed, but also by international institutions (EU Habitats Directive, Bern Convention) if the matter concerns transboundary cooperation or international obligations. The relevant national authorities should be made aware of status reports and recommendations (e.g. this publication).

Stakeholders and interest groups must be involved in lynx conservation and management at all levels, but the "Bonn expert group" should engage with them at international level. Obvious partner groups are the IUCN SSC Cat Specialist Group and the LCIE, and the EAZA Felid TAG. Regular contact should furthermore be established with the Federation of Associations for Hunting and Conservation of the EU (FACE), the International Council for Game and Wildlife Conservation (CIC), the World Wide Fund for Nature (WWF), Landowners' Association, Europarc/Alparc, Euronatur, Greenpeace, and others. These institutions should (1) be regularly informed about the conservation status of lynx, (2) attend international/Continental meetings, and (3) be invited to provide expertise and support.

The scientific cooperation between lynx researchers at European level is well functioning based on personal communication and cooperation at project level. Networks such as EUROLYNX (Heurich et al. 2021) are further facilitating cooperation. There are however two obvious requirements with regard to science and lynx conservation: (1) Social scientists must be involved in the lynx conservation group in the future. Although social and legal science research on large carnivore conservation has considerably increased over the past two decades, most papers relevant to lynx conservation are still from the natural science point of view. (2) Conclusions from research projects must be more directly considered in lynx conservation and management approaches. This requires first that policy and decision makers (and relevant interest groups) are informed about the scientific findings (see above).

Transboundary management plans as proposed by Linnell et al. (2008) are considered a useful tool to develop and coordinate transboundary cooperation. While the technical/scientific cooperation at international level works rather well, and monitoring is increasingly coordinated at metapopulation level (Molinari-Jobin et a. 2021), there are still very few transboundary conservation and management projects where the respective national institutions are engaged. Technical cooperation and international funding (e.g. EU LIFE or InterReg projects) for transnational projects is often a good start. The lynx expert group (e.g. in cooperation with NGOs) should engage more in the development of transboundary population management/conservation strategies and the related national action plans as implementation tools. It is important to define measurable goals/objectives at population level. However, national authorities are often scared by binding concrete international obligations that they need to enforce at the national level. In this respect, the "freedom within frames" principle (Linnell et al. 2008) should be applied allowing adopting population-level goals to national requirements.

Recommendations:

- In order to give the participants of the Bonn lynx symposium and workshop a face and a voice, it should be continued as a permanent lynx working group, e.g. affiliated with IUCN SSC specialist groups such as the Cat Specialist Group and the LCIE.
- This group should develop and maintain a number of practical protocols for lynx conservation and management as outlined under "Recommendations" above.
- Besides technical recommendations, the group should engage with other experts to develop concepts for a wider outreach and communication in order to reach the institution and interest groups mentioned above, but also the general public.

Concluding remarks

The final discussion at the Bonn lynx symposium and workshop revealed that the participants considered this review of the situation of lynx (see Proceedings in this issue) most useful and the conclusion and outlook (these Recommendations) a starting point for more targeted and coordinated work on lynx conservation. It is relatively easy to reach consensus within a group of like-minded experts, but it is much more challenging to engage with the relevant authorities, the interest groups and the civil society. This requires a long-term commitment and continuous dialogue between all parts of our society interested and concerned. These Proceedings summarise the present status of the Eurasian lynx in Continental Europe, and the Recommendations outline the strategic approach and provide guidance for practical cooperation. A report summarising the Bonn symposium and workshop was submitted to the Berne Convention, and on 6 December 2019, the Standing Committee has adopted the Recommendation No. 204 (2019) on the Conservation of the Eurasian lynx (*Lynx lynx*) in Continental Europe (https://rm.coe.int/2019-rec-204e-lynx/1680993e0b; see also Online Supporting Material Document D1). These Recommendations were hence reviewed, discussed and adopted by representatives of all countries considered in this report. These Proceedings and Recommendations will be used to inform and engage with the potential partners in lynx conservation as identified above. Reaching out to the public and national or local stakeholders requires messages adapted to the local situation, communicated in the respective languages and through the appropriate channels. This cannot be the task of an international group of specialists as the "Bonn Lynx Expert Group". However, these Recommendations may provide the basis for more targeted messages adapted to the situations in the countries of Western and Central Europe. Furthermore, the Recommendations also provide an agenda for the future work of the lynx experts that met at the Bonn lynx symposium and workshop.

Supporting Online Material SOM Document D1 is available at www.catsg.org

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[1] For the members of the Bonn lynx expert group see Appendix I

Annex I - List of participants of the Bonn conference

Name	Affiliation	Country
Anders, Ole	National Park Harz	DEU
Bagrade, Guna	SILAVA, Latvian State Forest Research Institute	LVA
Breitenmoser, Urs	KORA	CHE
Breitenmoser-Würsten, Christine	KORA	CHE
Brix, Mareike	EuroNatur Stiftung	DEU
Černe, Rok	LIFE-Project Lynx „Dinarisches Gebirge"/ forestry authority	SVN
Cirovic, Dusko	University Belgrad	SRB
Drouet- Houget, Nolwenn	OFB, Office français de la biodiversité	FRA
Fernandez-Galiano, Eladio	Council of Europe; Environment, Biodiversity, Cultural Routes	FRA
Germaine, Estelle	CROC (Centre de Recherche et d'Observation sur les Carnivores)	FRA
Heider, Christoph	HIT environmental foundation	DEU
Herdtfelder, Micha	Forestry research institution Baden-Württemberg (FVA)	DEU
Heurich, Marco	National Park Bayerischer Wald, University Freiburg	DEU
Hucht-Ciorga, Ingrid	State office of Nature, Environment and consumer protec-tion Nordrhein-Westfalen (LANUV)	DEU
Idelberger, Sylvia	Foundation Nature and Environment Rheinland-Pfalz (SNU), LIFE-Project	DEU
Klinga, Peter	University Zvolen	SVK
Klose, Moritz	WWF Germany	DEU
Krebühl, Jochen	Foundation Nature and Environment Rheinland-Pfalz (SNU)	DEU
Krojerová-Prokešová, Jarmila	Mendel-University Brno (Brünn)	CZE
Kubala, Jakub	Diana	SVK
Kutal, Miroslav	Mendel-University Brno (Brünn)	CZE
Melovski, Dime	MES, Macedonian Ecological Society	MKD
Middelhoff, Lilli	National Park Harz	DEU
Minarikova, Tereza	ALKA wildlife	CZE
Molinari- Jobin, Anja	KORA; The Progetto Lince Italia	CHE/ITA
Molinari, Paolo	KORA; The Progetto Lince Italia	CHE/ITA
Nowak, Carsten	Senckenberg research institute	DEU
Ohm, Judith	Foundation Nature and Environment Rheinland-Pfalz (SNU)	DEU
Ozolins, Janis	SILAVA, Latvian State Forest Research Institute	LVA
Premier, Joe	University Freiburg	DEU
Prüssing, Annina	Foundation Nature and Environment Rheinland-Pfalz (SNU), LIFE-Project	DEU
Reiners, Tobias	Senckenberg research institute	DEU
Rodekirchen, Anna-Maria	Bavarian State office of Enivronment	DEU
Ryser-Degioris, Marie-Pierre	Centre for Fish and Wildlife Health (FIWI), Universtiy of Bern	CHE
Schmidt, Krzysztof	Mammal Research Institute, Białowieża	POL
Shkvyria, Marina	Schmalhausen Institute, National Academy of Science of Ukraine	UKR
Sin, Teodora	The Association for the Conservation of Biological Diversity	ROU
Sindičić Magda	University Zagreb	HRV
Skrbinšek, Tomaž	University Ljubliana	SVN
Sliwa, Alex	EAZA Felid TAG chair	DEU
Tám, Branislav	Zoo Bojnice	SVK
Tiesmeyer, Annika	Federal Office for Environment, special field zoological species protection	DEU
Trajçe, Aleksander	PPNEA (Protection and Preservation of Natural Environment in Albania)	ALB
Trbojevic, Igor	University Banja Luka	BIH
Trbojevic, Tatjana	University Banja Luka	BIH
von Arx, Manuela	KORA Carnivore	CHE
Walsh, Katherine	Natural England	GBR
Weingarth, Kirsten	National Park Kalkalpen	AUT
Wölfl, Sybille	Lynx Project Bayern	DEU
Wölfl, Manfred	Bavarian State office of Environment	DEU
Zimmermann, Fridolin	KORA	CHE
Zlatanova, Diana	University Sofia "St. Kliment Ohridski"	BGR

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