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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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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-

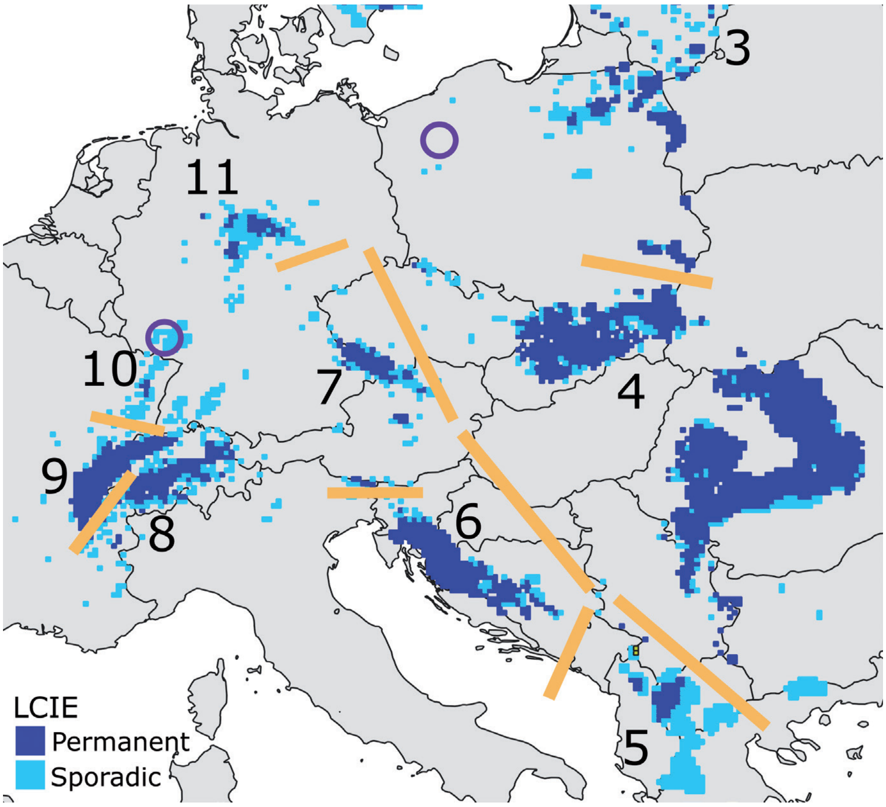

Fig. 1. Distribution map of Eurasian lynx in 2016 from Large Carnivore Initiative for Europe assessment (LCIE, Kaczensky et al. 2021) and delineation (orange lines, Chapron et al. 2014) of reintroduced (6 – Dinaric, 7 – Bohemian-Bavarian-Austrian, 8 –Alpine, 9 – Jura, 10 – Vosges-Palatinate, 11 – Harz 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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