No place to hide: Limited forest cover hampers the availability of suitable habitat for lynx in the Netherlands

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Abstract: In Europe, centuries-long of overharvesting and hunting of large herbivores and carnivores has resulted in extinctions of large mammals, such as the lynx (*Lynx lynx*). With the expansion of lynx distributions via recolonisation and reintroduction programmes, it is possible that the lynx will again recolonise the Netherlands. This study identified the most important predictors for lynx habitat suitability in the Netherlands and areas in the Netherlands where the ecological requirements of the lynx are met. The habitat suitability model showed that forest cover is the most important factor limiting the potential for the lynx in the Netherlands. The model shows that only four patches with suitable habitat of sufficient size to support at least one female lynx. Only one patch, covering the Veluwe, has enough room for four female territories and one male territory. The total range of suitable lynx habitat in the Netherlands amounts to 1054 square kilometres, although these patches are disconnected. While the species' selectiveness for forest might decrease over time through increased plasticity, the Netherlands has a very limited of amount of forestland, which is highly fragmented. We therefore conclude that the Netherlands' fragmented forests are not suitable for sustaining a viable lynx population at this moment.

Keywords: Eurasian lynx, recolonisation, reintroduction, habitat suitability model, the Netherlands.

Introduction

In Europe, centuries-long of overharvesting and hunting of large herbivores and carnivores has resulted in the local, regional and/or complete extinctions of large mammals, such as auroch (*Bos primigenius*), tarpan (*Equus ferus ferus*), lynx (*Lynx lynx*), brown bear (*Ursus arctos*) and wolf (*Canis lupus*) (Szafer 1968, Vereshchagin and Baryshnikov 1984, Berger et al. 2001, van Vuure 2002), although remnant populations of lynx have managed to survive in the Carpathian Mountains, the Balkans, Scandinavia and Eastern Europe (Breitenmoser 1998). In the second part of the 20th century, the Bern Convention and later the European Habitats Directive gave species such as the lynx some legal protection (Trouwborst 2010). Although poaching is still a threat to large carnivores (Liberg et al. 2012), lynx populations have increased and expanded their distribution throughout Europe over the last four decades. In the European large carnivore census of 2012, lynxes were distributed over 23 countries and can be grouped into ten subpopulations, five of which are the result of reintroduction programmes (Kaczensky et al. 2013). This information has recently been updated for 2012-2016, and according to this latest update the total number of lynxes in Europe (excluding the populations in Russia and Belarus) is estimated to be between 8,000-9,000 individuals (European Commission 2019; figure 1).

With the expansion of lynx distributions via recolonisation and reintroduction programmes, and the knowledge that the lynx lived in the Netherlands in the past (Groot Bruinderink 1997), it is possible that lynx will again recolonise the Netherlands in the future, be it naturally or through human intervention (Groot Bruinderink 1997, Groot Bruinderink et al. 2006). Because of this, it is of scientific interest to identify areas where lynx could most likely live in the Netherlands. An earlier exploratory study, based on literature analysis and expert judgement, assessed the possibilities of reintroducing the lynx in the Netherlands (Mulder 1992). However, this study was limited to the Veluwe (the Netherlands' largest forest) and was not able to make use of the potential of currently available geographical information systems (GIS) to fully assess the potential of the Netherlands for lynx.

GIS analysis can assess the potential distribution of lynx populations by using habitat suitability models. Hirzel & Le Lay (2008) define habitat suitability models as operational applications of the ecological niche, using environmental variables to predict the presence/absence and the abundance of a species throughout a study area. A habitat suitability model can cover both natural and man-made, environments and take into account constraining factors, such as the presence of urban areas, geographical barriers and human disturbance, and beneficial factors, such as vegetation type, food availability and corridors. To accurately predict the suitability of habitats, current habitat use is analysed, often by use of multivariate analysis, after which a predictive model can be produced and validated (Mladenoff et al. 1999, Schadt et al. 2002, Huck et al. 2010).

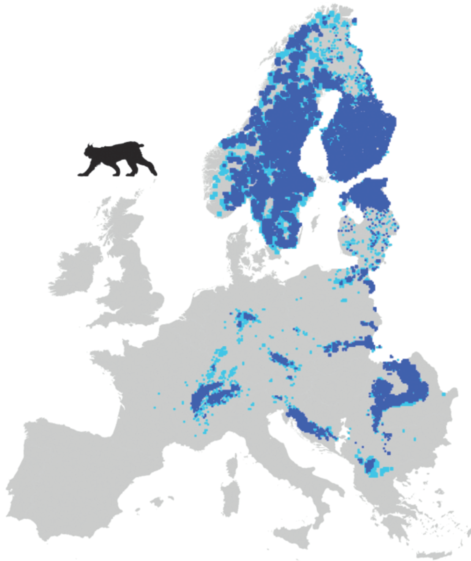

Figure 1. Eurasian lynx distribution in Europe 2012-2016. Dark blue cells: permanent occurrence. Light blue cells: sporadic occurrence. *From: European Commission 2019.*

In this study, we try to identify the most important predictors for lynx habitat suitability in the Netherlands and to identify areas in the Netherlands that meet the ecological requirements of the lynx.

Methods

To build the habitat suitability model of lynx in ESRI ArcGIS 10.0, we used the parameters that have been found to be the best predictors in validated habitat suitability models of the lynx in Europe and North America: land use, human population density, road density and forest cover (Glenz et al. 2001, Schadt et al. 2002). Prey density was not considered a potential limiting factor, as the main prey species (roe deer, hare and rabbits) are abundantly available throughout the Netherlands.

The land-use map used in this study was the LGN6 map from Alterra Wageningen UR. We transformed all land use classes into five general classes: agricultural land, urban areas, water bodies, forest and other nature areas. For computational reasons, we reduced the resolution from a 25x25 metre to a 250x250 metre grid. When multiple land types of land cover existed in one grid cell, the most dominant was expressed.

Human population densities were extracted from data from the Dutch Agency for Statistics (CBS). The vector-based map was converted into a 25x25 metre grid map and the resolution of the grid map was then reduced to a 250x250 metre grid to align the scale with the land use map. By first converting the data into a high-resolution grid and then reducing it to a lower resolution, we softened the harsh edges in population density between adjacent polygons.

The TOP10NL map of 2011 was used to calculate road density from primary and secondary roads. From this map, we selected all paved roads suitable for motorised traffic. We made a 250x250 metre grid and inserted the road dataset into this grid and then calculated the road length (in kilometres) within each grid cell.

The base maps of the parameters were merged using the union function. We deleted all grid cells with no land cover. In total, habitat suitability was analysed for 50,168 250x250 metre grid cells.

From the base map we identified all the grid cells with a human population of 25 people or more, a road density that exceeded 500 metres per square kilometre, had no water or were identified as urban areas (Schadt et al. 2002, Basille et al. 2009, Huck et al. 2010). Based on the resulting areas, we used the random point creator and buffered these points with a diameter of one kilometre. We then calculated the percentage of forest cover and percentage of coverage with agricultural lands within each circle. Lynx require at least 50% forest cover and can deal with a maximum of 10% agricultural lands (Schadt et al. 2002, Basille et al. 2009, Huck et al. 2010). We selected all circles that met these requirements and dissolved them with their neighbouring patches into bigger polygon patches. Lynx require territories of an average 100 km^2, with a minimum of about 60 km^2 for female lynx and more for male territories (Schadt et al. 2002, Molinari-Jobin et al. 2007, Schmidt et al. 2009). Territories can overlap across sexes. Of the areas that met all the parameters, we selected the patches that had the minimum size of 60 square kilometres.

Validation of the model is, unfortunately, not yet possible as there are no wild living lynxes in the Netherlands. Therefore, we made five extra maps to test the sensitivity of the habitat suitability models to changes in the most important factors; forest cover and road density. Whereas lynx normally require at least 50% forest cover, we also tested for 12.5%, 25% and 37.5%. In addition to the 500 m per square kilometre road density we also tested for 400 and 600 metres of road per square kilometre. As road density and human population density are known to strongly covariate (Glover & Simon 1975), we assumed this would also cover the effects of population density.

Results

The map resulting from the habitat suitability model (figure 2) shows that when all habitat demands are met, the Netherlands has five patches that can sustain at least one territory. The four smaller patches could not sustain a male territory and only one patch (in the Veluwe) could sustain a male territory next to several female territories. The total range of suitable lynx habitat amounts to 1054 square kilometres. However, these patches are not connected with each other.

The sensitivity analysis showed no signifi-

Figure 2. The maximum potential distribution of lynx in the Netherlands when taking all habitat demands into account (only grid cells with: road cover <500, human population >25, forest cover >50%). The total area with suitable area over the four patches is 1054 km^2. The four smaller patches cannot sustain a male territory, only the largest patch (the Veluwe) can sustain a male territory next to several female territories. *Map: G. Lelieveld, Vrije Universiteit / Alterra WUR.*

cant changes after changing the road density parameter. However, the sensitivity analysis did show that the minimum requirement of 50% forest cover over an area of at least 60 square kilometres was the most limiting factor for the suitability of habitat for lynx, as shown in figure 3. The maps show that the amount of suitable habitat for lynx increased from 1054 km^2 to 1575, 2275 and 4163 km^2 respectively, under the different selected criteria for forest cover.

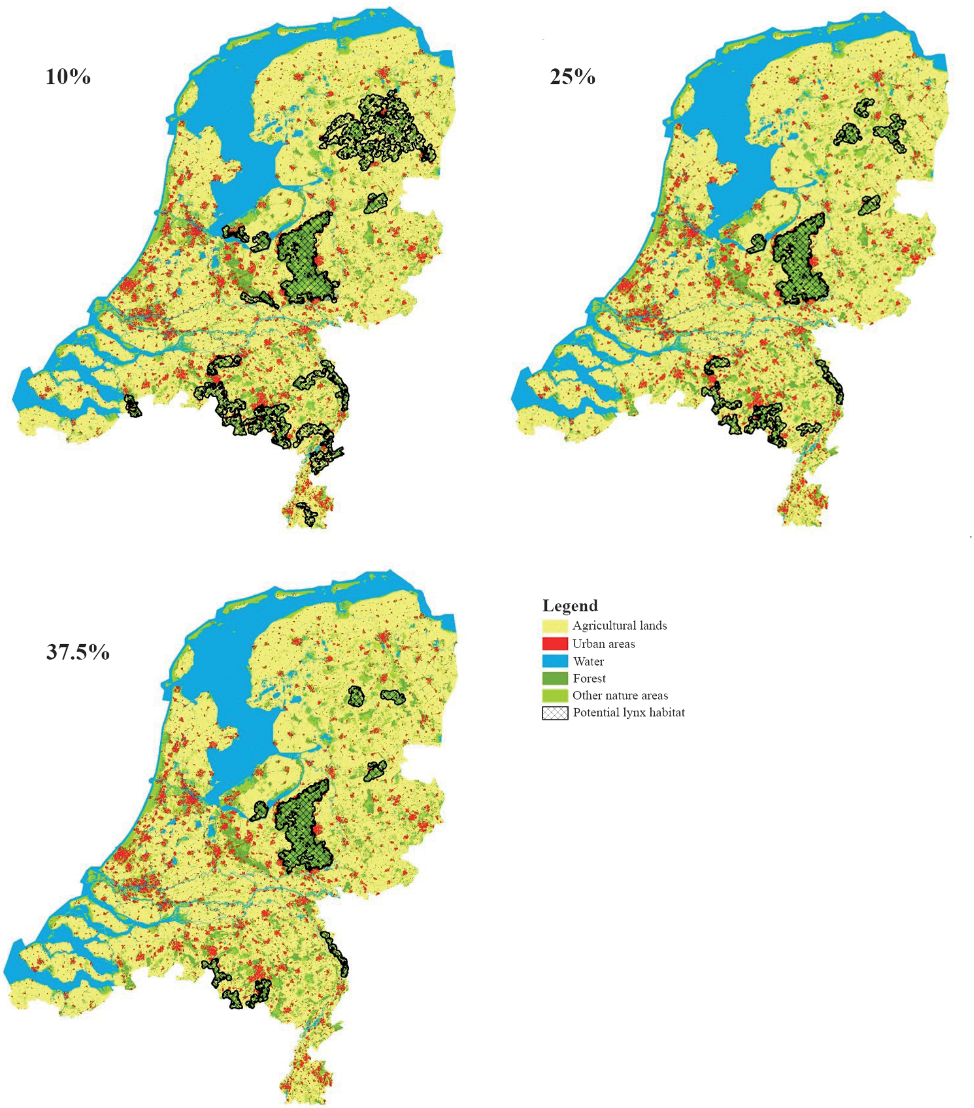

Figure 3. Output of the sensitivity analysis for the potential distribution of lynx assuming its tolerance to lower levels of forest cover (37.5%, 25% and 10% respectively) (with no maximum for cover of agriculture). *Maps: G. Lelieveld, Vrije Universiteit / Alterra WUR.*

Discussion

This study shows that habitat suitable for the lynx in the Netherlands is limited to a small number of isolated patches. This is in line with the assessment of Mulder (1992), although the results of this study more clearly and objectively show the most limiting factor: the low forest cover throughout the Dutch landscape, which would severely restrict the viability of a lynx population in the Netherlands. Because of this, the lynx would not be able to achieve a sustainable population in the Netherlands, unless the country's forests are actively reconnected. There has been policy on reconnecting nature areas in the Netherlands for 25 years, but it is currently inadequate to support a viable lynx population. Limited forest cover might also be a constraint on the expansion of lynx populations elsewhere in Europe. The latest census (Kaczensky et al. 2013), which shows trends in the ten European lynx populations, reveals an increase in the lynx populations in Finland and the Jura Mountains, with the others remaining stable or even decreasing. It seems that legal protection by itself is not enough to restore lynx populations to their historic ranges (Breitenmoser 1998). As the lynx is highly averse to open areas, fragmented landscapes might prove a barrier to its dispersal. The lynx also finds it difficult to hunt in highly fragmented landscapes. Stahl et al. (2002) found that lynx were eight times less likely to attack sheep in meadows that were at least 250 meters away from forest than those immediately adjacent to forest cover. This strengthens the outcomes of the sensitivity analysis, which shows the lynx to be highly sensitive to changes in forest cover. This suggests that the restoration of large continuous forests in Europe might well prove to be an important factor in restoring European lynx populations.

In the habitat suitability analysis, several generalisations were necessarily made that might have influenced the results. First, the human population dataset was based on the number of people per neighbourhood, a more precise human population would have given more accurate outcomes. Also, all paved roads were given an equal weighting in this study, due to unavailability of data there was no correction for traffic intensity. In addition, minimum territory size for the lynx was based on the needs of females as male lynx territories usually cover several female territories. All these generalisations simplified reality for the purposes of modelling. To test whether these generalisations overly influence the model the model could be validated using lynx populations abroad, but most of the relevant data is difficult to access.

In this study, we solely focussed on ecological suitability of habitat for lynx. The European large carnivore census (Kaczensky et al. 2013) also featured the results of a questionnaire in which European experts were asked to identify the major threats facing large carnivores face in their countries. Almost all lynx experts ranked low acceptance and persecution as the biggest threats to the species (Kaczensky et al. 2013). The low acceptance of lynx might provide an extra limitation on its dispersal capacity. Molinari-Jobin (2003) argues that for lynx to spread across barriers and found a new (sub)population, a relatively strong stimulus is needed, such as strong demographic pressure that would drive emigration from the source population. "However", she states, "high local lynx abundance results generally in a hefty controversy, as local people do not accept peak lynx densities" (Molinari-Jobin 2003).

It is possible that individual lynx will show up in the Netherlands, as the fragmented lynx populations in Western Europe are slowly expanding (Kaczensky et al. 2013), although at the time of writing (March 2019) there have been no verified sightings of lynx in the Netherlands. This study has only focussed on potential suitable habitat within the Netherlands itself, although it is possible that the lynx may find suitable habitat patches in the border regions with Germany or Belgium. Due to limited access to the relevant data for Germany and Belgium, such an assessment was beyond the scope of this study.

Conclusions

This study assesses the viability of the lynx returning to the Netherlands. Our habitat suitability analysis shows that the Netherlands has only four suitable (and unconnected) habitat patches. The study also shows that the Eurasian lynx's strong preference for forest is the most limiting factor. This preference for forest might decrease over time through increased plasticity, although the amount of forest in the Netherlands is low and highly fragmented. Therefore, we conclude that the fragmented forests of the Netherlands cannot sustain a viable lynx population at this moment.

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References

Basille, M., I. Herfindal, H. Santin-Janin, J.D.C. Linnell, J. Odden, R. Andersen, K. Arild Høgda & J.-M. Gaillard 2009. What shapes Eurasian lynx distribution in human dominated landscapes: Selecting prey or avoiding people? Ecography 32: 683-691. DOI: 10.1111/j.1600-0587.2009.05712.x.

Berger J, J.E. Swenson & I.L. Persson 2001. Recolonizing carnivores and naive prey: Conservation lessons from Pleistocene extinctions. Science 291: 1036-1039.

Breitenmoser, U. 1998. Large predators in the Alps: The fall and rise of man's competitors. Biological Conservation 83: 279-289. DOI: 10.1016/S0006-3207(97)00084-0.

European Commission 2019. Status of large carnivore populations in Europe 2012-2016. URL: http://ec.europa.eu/environment/nature/conservation/species/carnivores/conservation_status.htm; viewed 12 June 2019.

Glenz, C, A. Massolo, D. Kuonen & R. Schlaepfer 2001. A wolf habitat suitability prediction study in Valais (Switzerland). Landscape and Urban Planning 55: 55-65.

Groot Bruinderink, G.W.T.A. 1997. De Veluwe niet lynx laten liggen: een beschouwing omtrent de wenselijkheid van herintroductie van de lynx (*Lynx lynx*) op de Veluwe. Mededelingen No. 31. Nederlandse Commissie voor Internationale Natuurbescherming: 35-39.

Groot Bruinderink, G.W.T.A., H. Kuipers, D.R. Lammertsma, K. DeSmet, M. Petrak & J.H. Eylert 2006. Met stille trom? Nederland en de Europese lynx. De Levende Natuur 107: 37-40.

Hirzel, A.H. & G. Le Lay 2008. Habitat suitability modelling and niche theory. Journal of Applied Ecology 45: 1372-1381. DOI: 10.1111/j.1365-2664.2008.01524.x.

Huck, M., W. Jędrzejewski, T. Borowik, M. Miłosz-Cielma, K. Schmidt, B. Jędrzejewska, S. Nowak & R.W. Mysłajek 2010. Habitat suitability, corridors and dispersal barriers for large carnivores in Poland. Acta Theriologica 55: 177-192. DOI: 10.4098/j.at.0001-7051.114.2009.

Glover, D. R., and J. L. Simon. 1975. Effect of Population Density on Infrastructure - Case of Road Building. Economic Development and Cultural Change 23: 453-468.

Kaczensky, P., G. Chapron, M. von Arx, D. Huber, H. Andrén & J.D.C. Linnell (eds) 2013. Status, management and distribution of large carnivores – bear, lynx, wolf & wolverine – in Europe. European Commission.

Liberg, O, G. Chapron, P. Wabakken, H.C. Pedersen, N.T. Hobbs & H. Sand 2012. Shoot, shovel and shut up: Cryptic poaching slows restoration of a large carnivore in Europe. Proceedings of the Royal Society B - Biological Sciences 279: 910-915. DOI: 10.1098/rspb.2011.1275.

Mladenoff, D.J., T.A. Sickley & A.P. Wydeven 1999. Predicting gray wolf landscape recolonization: Logistic regression models vs. new field data. Ecological Applications 9: 37-44.

Molinari-Jobin, A., F. Zimmermann, A. Ryser, P. Molinari, H. Haller, C. Breitenmoser-Würsten, S. Capt, R. Eyholzer & U. Breitenmoser 2007. Variation in diet, prey selectivity and home-range size of Eurasian lynx *Lynx lynx* in Switzerland. Wildlife Biology 13: 393-405.

Mulder, J.L. 1992. De lynx nog niet los, Nederlandse natuur te klein voor lynxen. Rapport Natuurmonumenten. Oktober 1992. URL: http://mulder-natuurlijk.nl/publicaties/rapporten/LYNX_NM_definitief.pdf.

Schadt, S., E. Revilla, T. Wiegand, F. Knauer, P. Kaczensky, U. Breitenmoser, L. Bufka, J. Cerveny, P. Koubek, T. Huber, C. Stanisa & L. Trepl 2002. Assessing the suitability of central European landscapes for the reintroduction of Eurasian lynx. Journal of Applied Ecology 39: 189-203.

Schmidt, K, W. Jędrzejewski, H. Okarma & R. Kowalczyk 2009. Spatial interactions between grey wolves and Eurasian lynx in Białowieza Primeval Forest, Poland. Ecological Research 24: 207-214. DOI: 10.1007/s11284-008-0496-y.

Stahl, P., J. M. Vandel, S. Ruette, L. Coat, Y. Coat, and L. Balestra. 2002. Factors affecting lynx predation on sheep in the French Jura. Journal of Applied Ecology 39:204-216.

Szafer, W. 1968. The Ure-ox, extinct in Europe since the seventeenth century: An early attempt at conservation that failed. Biological Conservation 1: 45-48.

Trouwborst, A. 2010. Managing the carnivore comeback: International and EU species protection law and the return of lynx, wolf and bear to Western Europe. Journal of Environmental Law 22 (3): 347-372. DOI: 10.1093/Jel/Eqq013.

van Vuure, T. 2002. History, morphology and ecology of the Aurochs (*Bos taurus primigenius*). Lutra 45 (1): 3-17.

Vereshchagin, N.K. & G.T. Baryshnikov 1984. Quaternary mammalian extinctions in northern Eurasia. In: P.S. Martin & R.G. Klein (eds). Quaternary Extinctions: 483-516. University of Arizona Press, Tuscon, Arizona, USA.

Samenvatting

Het huidige bosareaal in Nederland is onvoldoende voor vestiging van de lynx

In Europa heeft eeuwenlange overexploitatie en jacht van grote herbivoren en roofdieren geleid tot het uitsterven van grote zoogdieren zoals de lynx (*Lynx lynx*). Met de uitbreiding van het leefgebied van lynxen via rekolonisatie en herintroductieprogramma's is het mogelijk dat lynxen Nederland opnieuw koloniseren. Deze studie identificeert de belangrijkste voorspellers voor geschikt leefgebied voor lynxen in Nederland en de gebieden die voldoen aan deze ecologische vereisten. Het habitatgeschiktheidsmodel laat zien dat bosareaal de belangrijkste limiterende factor is voor potentieel leefgebied voor lynxen in Nederland. Het model laat zien dat slechts vier gebieden met geschikt leefgebied van voldoende grootte zijn om tenminste één vrouwelijke lynx te herbergen. Eén gebied, de Veluwe, heeft voldoende ruimte voor vier territoria van vrouwelijke lynxen met, overlappend, één territorium van een mannelijke lynx. De totale oppervlakte van geschikt leefgebied voor lynx in Nederland is 1054 vierkante kilometer; deze gebieden staan echter niet in verbinding met elkaar. Hoewel de afhankelijkheid van de soort voor bosareaal in de toekomst afneemt door toenemende plasticiteit van de soort, heeft Nederland een zeer beperkt areaal aan bos, dat bovendien gefragmenteerd is. Wij concluderen dat het gefragmenteerde bosareaal van Nederland op dit moment ongeschikt is voor een levensvatbare populatie van de lynx.

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