Habitat suitability for the reintroduction of the European mink (*Mustela lutreola*) in the Netherlands

Luuk Zwartenkot[1], Julia Schepers[1], Saskia Ruth[1], Glenn Lelieveld[2] & Pim van Hooft[3]

[1] Dutch Mammal Society, Toernooiveld 1, NL-6525 ED Nijmegen, the Netherlands,
e-mail: luukzwartenkot1@gmail.com
[2] Averti Ecologie BV, the Netherlands
[3] Wildlife Ecology and Conservation Group, Wageningen University,
Droevendaalsesteeg 3a, NL-6708 PB Wageningen, the Netherlands

Abstract: As one of the most critically endangered mammals in Europe, the European mink (*Mustela lutreola*) is in need of urgent conservation actions to ensure its survival. With the disappearance of the American mink (*Neogale vison*) in the Netherlands, one of the European mink's primary threats has been eliminated here, creating an opportunity for its reintroduction. The aim of this study was to identify the potentially most suitable areas for a reintroduction in the Netherlands. To this end, a rule-based habitat suitability model was created based on land use, natural waterways, road density and human presence. The Netherlands seems to have a considerable number of suitable areas for reintroduction, although their favourability varies depending on factors such as fragmentation and muskrat (*Ondatra zibethicus*) control efforts. Wetland areas in the north of the Netherlands were generally identified as the most suitable for a reintroduction, with the Weerribben-Wieden and wetlands at the border of the provinces of Groningen and Drenthe as standout areas. Lowland peat areas in the west with high densities of American crayfish (*Procambarus clarkii* and *Procambarus acutus*) are also good options, although fragmentation and the high intensity of muskrat trapping present notable challenges here. Further investigation into the potential release sites is recommended to examine habitat characteristics in greater detail, assess connectivity and get a grip on the local political and societal dynamics that will play an important role in the success of a reintroduction.

Keywords: European mink, *Mustela lutreola*, reintroduction, habitat suitability analysis, the Netherlands.

Introduction

Biodiversity worldwide is declining due to a range of factors, one of which is the spread of invasive species (Mollot et al. 2017). While some mammals in Europe are recovering due to legal protection and improved habitat conditions, others continue to decline due to the impact of invasive species. One such example is the European mink (*Mustela lutreola*), which is considered one of Europe's most endangered mammals and which is listed as

Critically Endangered on the IUCN Red List (Põdra et al. 2025). It is protected as an Annex II and Annex IV species in the EU Habitats Directive. The main threat to the species is the invasive American mink (*Neogale vison*), which was brought to Europe for the fur trade, where it has driven the European mink to near extinction. As a larger and more adaptable species, the American mink is able to outcompete its European counterpart, both through direct competition and interference competition (Maran 2007, Santulli et al. 2014, Põdra et al. 2025). Moreover, it is a known carrier of Aleutian disease virus (ADV), to which the European mink is particularly vul-

nerable (Maran 2007). Importantly, the disappearance of the European mink in many areas cannot be solely attributed to the presence of the American mink. However, by occupying its niche, the American mink has prevented a resurgence of the European mink despite improved habitat conditions and legal protection (Maran & Henttonen 1995).

In many European countries the American mink has become widespread and has taken over the niche of the European mink. As a result, the European mink now occupies only a fraction of its original range, with confirmed current occurrence only in southwestern France, northern Spain, the Danube delta in Romania and Ukraine, and the Dniester delta and the Carpathians in Ukraine (Harrington & Maran 2024, Mitchell-Jones et al. in press). In addition, there is an introduced population on the island of Hiiumaa in Estonia and there are some isolated populations in Russia (Harrington & Maran 2024). All populations are highly isolated and increasingly threatened by the encroachment of the American mink (Põdra & Gómez 2018).

Many countries are struggling to find effective solutions to control the American mink. In the Netherlands however, the American mink revealed an interesting trend in 2021. After the accelerated closing of American mink farms in 2020 due to the spread of COVID-19, the population of feral American minks showed a rapid decline. By 2021, the American mink had almost been completely eradicated from the Netherlands (La Haye & Janssen 2025). Small founder populations, combined with intensive control using muskrat (*Ondatra zibethicus*) traps are likely the reasons that the American mink has never been able to build up a substantial population in the Netherlands. The closing of the mink farms meant that there was no more influx of new individuals, resulting in extinction on a national scale.

Given the critically endangered status of the European mink, it is expected that the species will not persist without serious conserva-

tion actions (Maran 2007, Põdra et al. 2025). So far there have been reintroduction programmes in Estonia and Germany. In Estonia, the island of Hiiumaa was cleared from American mink, followed by European mink releases between 2000 and 2016 (Maran et al. 2009). A stable population size has since been observed. In Germany, reintroductions were done in Saarland (Peters et al. 2009) and near Steinhuder lake (Lange et al. 2022), but little is known about the state of these populations.

The rapid decline of the American mink in the Netherlands (La Haye 2025) sparked an idea: with one of the main threats to the European mink almost having vanished, could this open the door for a reintroduction of the European mink? This led to a feasibility study carried out by Lange et al. (2022), in which they studied the possibility of reintroducing the European mink in the Netherlands, based on the IUCN guidelines for reintroductions. They concluded that most threats to the European mink in the Netherlands have been mitigated, but scrupulous control of American mink remains essential. They argued that the European mink is unlikely to pose a large risk to native Dutch species such as meadow birds, as predation of European mink on medium-sized birds is limited. Although some competition with other mustelids may occur, the European mink's diet differs substantially from that of species like the stoat (*Mustela erminea*) and the western polecat (*Mustela putorius*). Moreover, the species coexists with these relatives throughout much of its current range, suggesting that interspecific competition would be minimal. Lange et al. also argued that the Netherlands, with its many wetlands, supposedly offers very suitable habitat for the species, as it is a riparian mammal. The Biesbosch and Weerribben-Wieden were proposed as potential candidate areas. However, the importance of a habitat suitability analysis was emphasized in order to identify the most promising areas for a reintroduction. This study aims to address that need.

The Netherlands is currently among the

lowest ranking countries of the EU member states regarding the state of its nature and it is not on track to meet its biodiversity targets (Nationaal Dashboard Biodiversiteit 2025). As a predator high in the trophic system, the European mink would therefore be a valuable addition to the Dutch river delta ecosystem. The species may also provide an important ecosystem service, as it has been found to exhibit signs of crayfish preference (Haage et al. 2017). It could therefore potentially aid in the control of the invasive red swamp crayfish (*Procambarus clarkii*) and white river crayfish (*Procambarus acutus*) in the Netherlands.

Youngman (1982) has critically reviewed the information on the distribution of the European mink. His conclusion for the Netherlands is that there is only one proven record: a skull from about 2300 BC found in a hunting camp at Vlaardingen (Van Bree 1961). This is more than four millennia before present. However, based on oral reports from fishermen, Van Bree (1976) suggests that the European mink has disappeared from the Netherlands towards the end of the 19th century. A mounted specimen in the collection of the Übersee-Museum in Bremen, shot in the area of Blockland near Bremen in 1884, further supports the species' presence in the wider region during the 19th century. Blockland is about 110 kilometres from the Dutch-German border. Confusion with polecats may be a reason for the scarcity of historical records of European minks in the Netherlands, as this reportedly also occurred in eastern Europe (Dr. Tiit Maran, personal communication).

Given its critical conservation status, the European mink presents an excellent opportunity for the Netherlands to fulfil a moral obligation and contribute to the recovery of a globally threatened species. Species reintroductions however require high investments, which means that careful planning is crucial. An important first step is identifying the most suitable areas for reintroduction. Predictive models can be used for this, thereby optimizing reintroduction efforts, increasing the like-lihood of long-term success (Hunter-Ayad et al. 2020). In this study, we conducted a habitat suitability analysis for the European mink in the Netherlands, providing a comprehensive overview of potentially suitable areas for its reintroduction. This is the first habitat suitability analysis for the European mink in the Netherlands, and no comparable habitat suitability studies from other countries have been published for this species to date.

Methods

Model choice

Habitat suitability modelling can be defined as the application of the ecological niche concept by predicting the likelihood of a species' occurrence based on environmental variables (Hirzel & Le Lay 2008). Recent years have seen the rise of habitat modelling using presence data by relating current species occurrence to environmental variables (Phillips et al. 2004). This is however not possible for the European mink in the Netherlands due to its current absence and therefore a lack of presence data. Extrapolating from the current distribution of the European mink is also not suitable, because its distribution is not only determined by suitability of habitat, but also – in some areas perhaps even more so - by the absence of American mink (Maran & Henttonen 1995). In addition, the Dutch landscape has been modified considerably, which means that a release area may constitute a relatively new environment. Therefore, correlative models may underestimate habitat suitability if the habitat is good but falls outside the range of the data used to train the model (Hunter-Ayad et al. 2020). Past American mink presence in the Netherlands could be used as a proxy for European mink, but the distribution of American mink in the Netherlands correlated strongly with the locations of mink farms, rather than the most favourable habitat (Dekker & Hofmeester 2014).

To the best of our knowledge, there are no habitat suitability analyses for European mink that can serve as an example for this study. For the reintroduction in Estonia, the predicted suitability of the island of Hiiumaa was estimated based on surveys on prey and shelter availability combined with expert judgement (Dr. Tiit Maran, personal communication). Furthermore, the presence of American mink was an indication that the island would be suitable for European mink after eradication of American mink.

For the habitat suitability analysis in this study, we used a rule-based model. This is a model based on habitat preferences derived from literature combined with expert judgement. Rule-based suitability modelling has been applied in marine and aquatic suitability modelling, but also increasingly for terrestrial species (Gwynn & Symeonakis 2022).

Habitat preferences

The most important habitat preferences for European mink were identified based on literature and expert judgment, with input from Dr. Tiit Maran (European mink expert) and Dick Klees (carnivore expert, Studio Wolverine). These habitat preferences are:

Land use. European minks are restricted to natural habitats, which we define as areas with minimal human disturbance and a high presence of natural vegetation. They particularly favour wetland habitats with small woody vegetation, such as bramble bushes and reeds, which provide cover and are commonly used for nesting (Zabala et al. 2003, 2006, Palomares et al. 2017, Lange et al. 2022). In some studies, they have been found to avoid dense forests (Zabala & Zuberogoitia 2003, Fournier et al. 2008).

Natural waterways. As a semi-aquatic animal, the European mink is mainly active in the riparian zone. They settle their home range along waterways (Fournier et al. 2008, Palomares et al. 2017) and are mostly found less than 150 metres from a watercourse (Danilov & Tumanov 1976), but at times they can go up to 500 metres (Dr. Tiit Maran, personal communication). Palomares et al. (2017) found that females had small home ranges mainly in lagoons and small tributaries, whereas males also included river sections in their home ranges. The species has been found to be absent from canalised streams, likely due to a lack of shelter and prey sources (Maran & Henttonen 1995, Lodé 2002, Zabala et al. 2006). They are also prone to fragmentation, as their presence has been found to depend on non-fragmented main river stretches and the number of waterways free from barriers (Lode 2002, Zuberogoitia et al. 2013, Goicolea et al. 2022). Mink can reside near fast-flowing or slow-flowing water, provided the water remains unfrozen during winter (Dr. Tiit Maran, personal communication).

Roads. As with many mammal species, roads pose a serious risk to European mink. In Spain, road kills were the most common cause of death in the period 1990-2008 (Palazón et al. 2012). After trapping, the main mortality cause in western France was road kills in the period 1965-1997 (Lodé et al. 2001). In the Netherlands, road mortality is an especially large problem, as is illustrated by the otter (*Lutra lutra*): road mortality was the cause of death in roughly 87% of deceased otters found in the Netherlands (de Groot et al. 2023). European minks usually avoid passing through culverts, just like otters. This means that when moving along waterways they will cross roads over land which leads to road casualties (Dr. Tiit Maran, personal communication).

Human presence. The European mink is sensitive to human disturbance and therefore requires large undisturbed areas. Ortiz-Jiménez et al. (2021) found that European minks hid themselves for longer periods of time when being exposed to anthropic noises, as well as to the odor of dogs. However, due to their nocturnal and crepuscular activity pattern (Garin et al. 2002), the effect of daytime disturbance (e.g. recreation) may be limited.

Table 1. Habitat preferences used in the habitat suitability model.

Habitat preference	Included in model as	Unit	Data type	Year	Sources
Land use	Land use	Categorical	Raster (5x5m)	2023 & 2022	LGN 2023 (https://lgn.nl/bestanden) RIVM Natura2000+NNN (https://www.atlasleefomgeving.nl/groenkaart-van-Nederland)
Natural water-ways	Shoreline length	km/km^2	Polylines	2024	PDOK TOP10NL (https://www.pdok.nl/datasets)
Roads	Road density	km/km^2	Polylines	2024	PDOK TOP10NL (https://www.pdok.nl/datasets)
Human presence	Building density	m^2/km^2	Raster (5x5m)	2024	PDOK TOP10NL (https://www.pdok.nl/datasets)

Additional habitat preferences are recognized, but these were not included in the model for the following reasons:

Water quality. This can have a significant effect on especially carnivores due to bioaccumulation of pollutants (Borgå 2013). In the past the level of PCB pollution has been a threat to otters in the Netherlands (Broekhuizen & de Ruiter-Dijkman 1988). However, since the reintroduction of the otter (2002-2008) a viable population has established and the otter is rapidly increasing (de Groot et al. 2023). Apparently water quality is no bottleneck anymore for the otter in the Netherlands. Since European mink is less dependent on fish in its diet than otter, the effect of water quality could be even smaller and therefore it was not included in the model.

Prey availability. European minks have a varied diet consisting of crayfish, fish, voles, mice and more (Lange et al. 2022). Accurate nationwide occurrence data for most of these species is lacking, however. The wetlands of the Dutch river delta are characterized by a high primary productivity and mild winters, which results in high abundances of e.g. mice and crayfish. Therefore, it was assumed that prey availability is not a limiting factor in this model.

Absence of American mink. since the species has almost completely been eradicated in the Netherlands and the last remnant populations are expected to disappear soon, it was not included in the model.

The habitat preferences were included in the model as shown in Table 1. Land use and shoreline length per km^2 together are a proxy for potentially suitable habitat. Road density and building density were included as proxy variables for anthropic disturbance. We opted for building density instead of population density, as this better reflects the effect of recreation by including e.g. harbours and holiday parks.

The Netherlands must adhere to the Berne convention and several key EU regulations and directives aimed at the conservation of wildlife, including the Birds Directive, the Habitats directive and the Invasive Alien Species Regulation. To this end, 162 areas in the Netherlands have been designated as Natura 2000 sites, aimed at conserving the most valuable and threatened species and habitats. We chose not to include Natura 2000 sites as a direct input variable in the habitat suitability model, as their designation is already based on ecological value and could therefore bias the results by inflating suitability scores. Natura 2000 areas were considered afterward to evaluate how well these align with suitable habitats and to identify potential gaps for reintroduction planning.

Data preparation

The data used can be found in Table 1. The

Table 2. Weighted input maps for the habitat suitability model.

Input map	Pixel size	Transformation		Weight
Land use	100x100m	Unique categories:		3
		Land use type	Suitability	
		Buildings	1	
		Agriculture	3	
		Forest	7	
		Dunes	5	
		Heather / drifting sand	5	
		Raised bog	3	
		Other wetland vegetation	9	
		Reed vegetation	10	
		Forest in wetland	10	
		Shrub vegetation in wetland	10	
		Naturally managed agricultural land	9	
		Other grassland	6	
		Other shrub vegetation	8	
Shoreline length	500x500m	Continuous function: MSLarge		2
Road density	500x500m	Continuous function: MSSmall		1
Building density	500x500m	Continuous function: MSSmall		1

data was prepared in QGIS 3.36 Maidenhead. For land use, the LGN2023 map was simplified to only relevant categories using the reclassify tool. Because many Natura 2000 and NNN (Nature Network Netherlands) areas were classified in LGN as agricultural, a Natura 2000 + NNN map was added using the raster calculator. These areas were then classified as naturally managed agricultural land. Water surfaces were excluded from the land use map, since only shorelines are suitable, and these are already included in the shoreline length layer. The land use layer was resampled to a 100 x 100 m raster using the Warp tool. For shoreline length and road density, total length per 500 x 500 m grid cell was calculated using the Sum line lengths tool. Building density per 500 x 500m grid cell was calculated using Zonal statistics.

Suitability modelling

The habitat suitability maps were produced using the Suitability Modeler environment from the Spatial Analyst package in ArcGIS Pro 3.4. This tool transforms input maps into separate suitability maps which are then combined into one final suitability map. The input maps were transformed and weighted according to expert judgment, with input from Dr. Tiit Maran and Dick Klees, as detailed in Table 2. The weights for the input maps and suitability scores for the land use map are continuous, meaning that a land use type with score 9 is considered three times more suitable than a land use type with score 3. For road density and building density the input map was transformed using the MSSmall function (Minimum Slope to Smallest Cell). This function rescales input data based on the mean and standard deviation where smaller values in the input raster have higher preference. This transformation fits well for roads and buildings, as it helps to emphasize areas with low road and building density. For shoreline length the opposite function was used: MSLarge (Mean Slope to Largest Cell). This was done to emphasize areas with a high shoreline length per km². A sensitivity anal-

ysis was performed by testing the effect of weight variations on the output map.

Identification of suitable areas

Suitable areas were identified using the Locate tool in the Suitability Modeler. Here, the top 5, 10 and 15 contiguous areas were selected based on the highest suitability values for such areas. For the areas, a minimum of 50 km² was chosen. In addition, the tool requires an average size for the areas, which was set at 100 km². It is difficult to determine the minimum area size based on the requirements of a mink population, as this depends more on the total length of banks of watercourses and prey availability within the area than on the overall size of the area itself (Fournier et al. 2008). In this study, areas of at least 50 km² were generally considered sufficient, as these include the most important Natura 2000 sites in the Netherlands. For the shape of the areas, a pentagon was selected with 25% shape/utility trade-off. This setting balances two key objectives: maximizing ecological utility, by allowing the shape to better conform to landscape features such as linear fluvial areas (e.g. brook valleys) while maintaining a roughly circular form. A higher trade-off value (closer to 100%) would result in a more compact, circular shape, while a lower value (closer to 0%) would allow the shape to stretch more freely but potentially lead to highly irregular and narrow forms, which may be less desirable for a reintroduction site.

Results

In Figure 1A, the habitat suitability model for the Netherlands is displayed. The red areas, which are the least suitable, are mostly urban areas (Figure 1D). The yellow parts mostly consist of intensive agriculture. Some agricultural areas in the west show up as light green,

as a result of the high shoreline length in these areas (Figure 1C). Natural areas are generally green, with drier areas like the Veluwe being light green, whereas the wetter lowland areas are darker green (most suitable). The more elevated south and east of the Netherlands are generally unsuitable as it is too dry. As such, the 'wet axis' is clearly present in the model, reflecting the wet lowlands. Striking are the green areas in the north of the country. The lowland peat areas in the west of the Netherlands also stand out. Rivers, brook valleys and large lakes are not clearly distinguishable, possibly due to their relatively low shoreline length per square kilometre compared to wetland areas with many brooks and canals.

Scenarios for most suitable areas

Figure 2 shows scenarios for the most suitable areas according to the model. The north of the Netherlands seems to have the most suitable areas in close proximity to each other (Figure 2), suggesting that this could be a good option for a metapopulation. The top five areas are further discussed in Table 3, along with three other areas (labelled A, B and C in Figure 2) that are potentially interesting. Some areas are fully designated as Natura 2000 sites under the Habitats Directive, while others are only partially included or fall solely under the Birds Directive (Natura 2000 Gebieden (LVVN, retrieved on 5-9-2025). Inclusion in the Habitats directive is favourable for a reintroduction, because then specific conservation measures will need to be taken for the European mink, like habitat restoration and reduction of human disturbance.

Discussion

This study has provided a comprehensive overview of the suitability of the Netherlands for a reintroduction of the European mink. The model output serves as a good baseline for
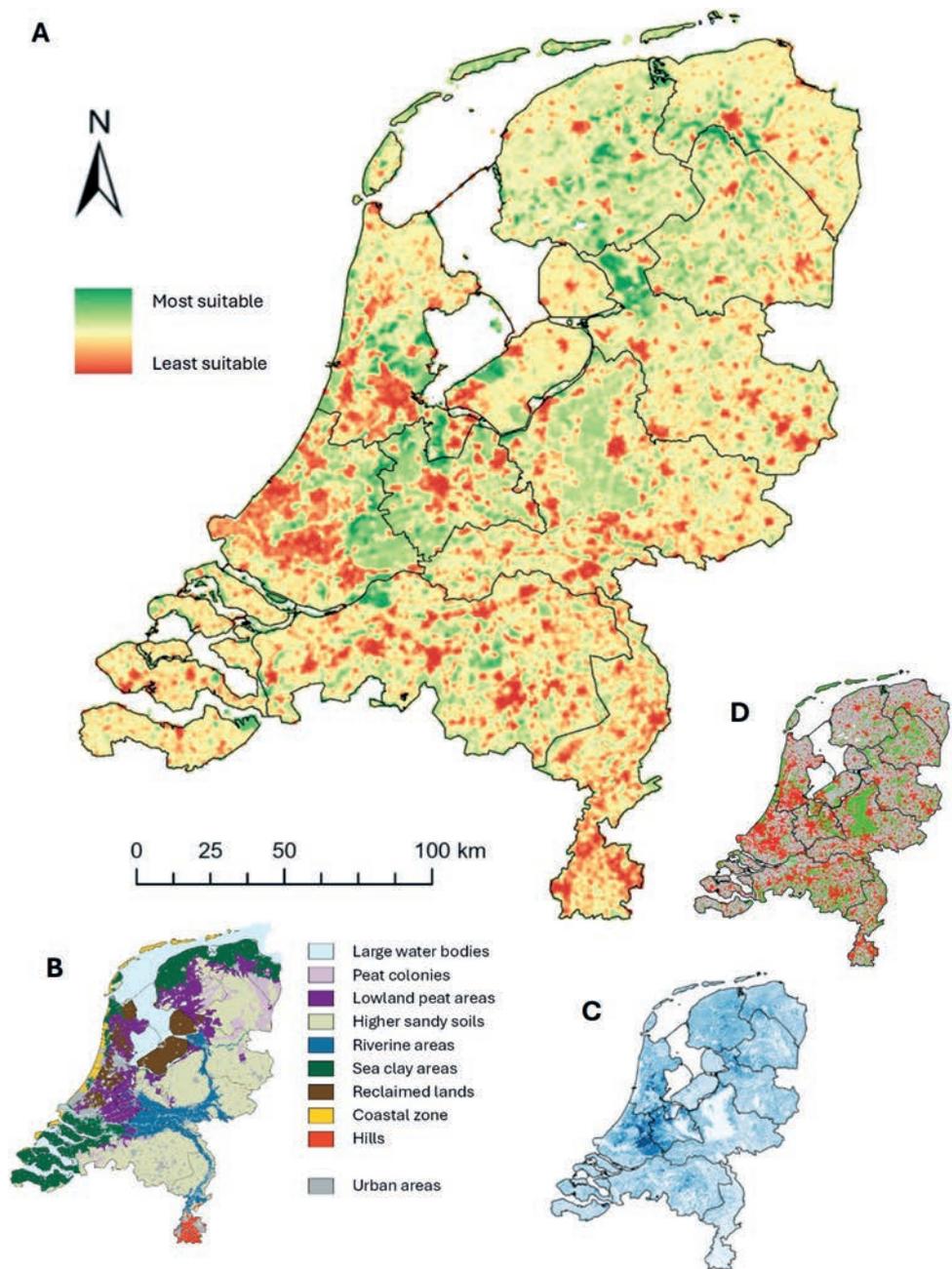
Figure 1. (A) Habitat suitability map for the European mink in the Netherlands. Suitability is based on land use (weight 3), shoreline length per km² (weight 2), road density and building density (both weight 1). Red areas indicate the poorest habitat and green areas show the most suitable habitat. (B) Reference map of physical-geographical regions of the Netherlands (source: Statistics Netherlands). (C) Map of shoreline length per km², with darker areas having a higher shoreline length per km². (D) Simplified land use map of the Netherlands, with red being urban areas, green natural areas and grey agricultural areas.
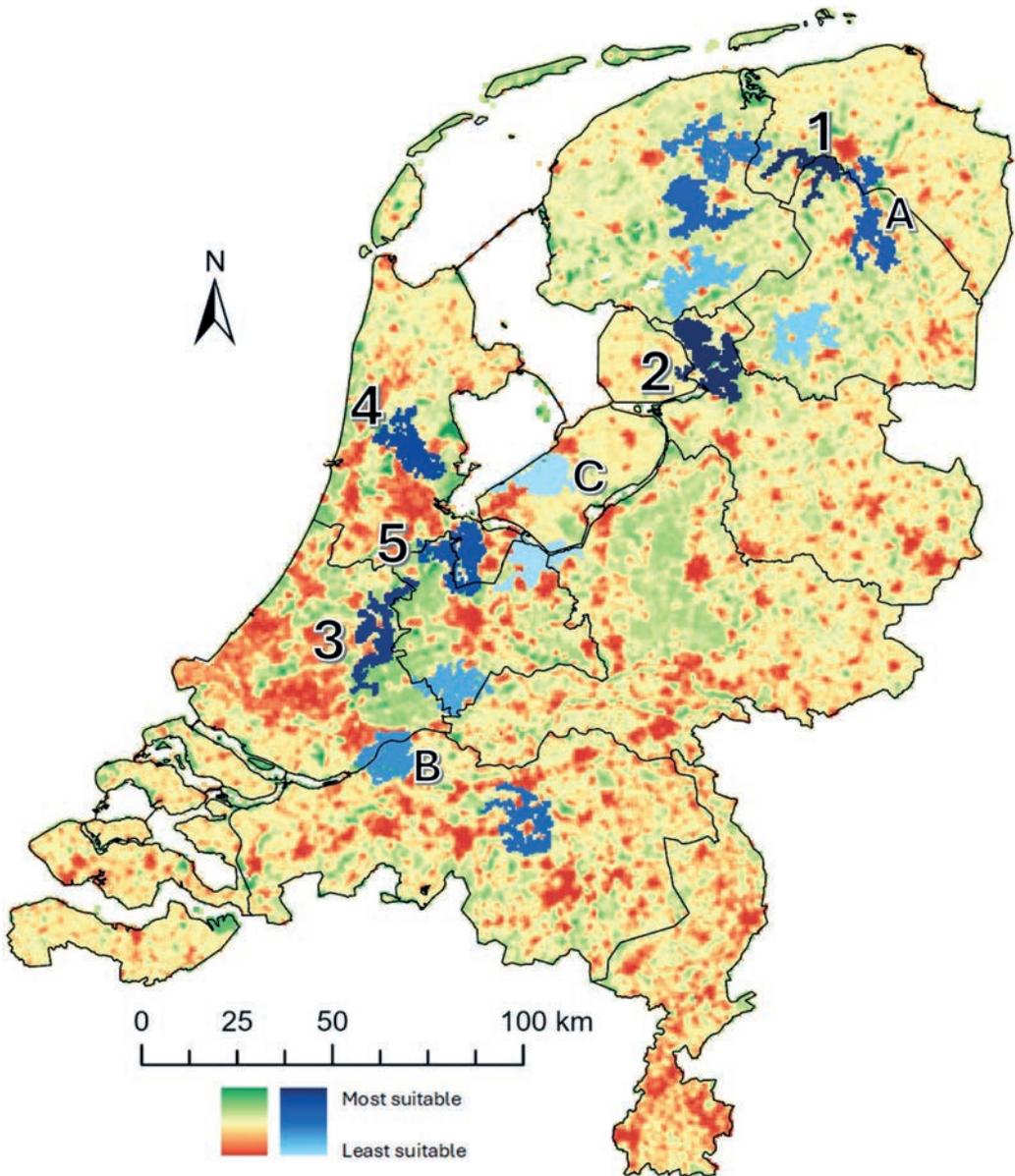
Figure 2. Habitat suitability map for the European mink in the Netherlands overlayed with the most suitable areas in blue. Shown are the top 15 contiguous areas of 50-250 km^2 with the highest suitability score. The darker blue the area, the higher the suitability score. The top five highest scoring areas are numbered and further discussed in the text, along with three other potentially interesting areas which are labelled A, B and C.

a suitability assessment, but each area comes with specific benefits and merits that are not reflected in the model. Here, we will go into detail on this. Notably, the high intensity of

muskrat trapping in certain areas (Figure 3) poses a problem for a reintroduction of the European mink. The susceptibility of mink to these lethal traps is evident from the cap-

Table 3. An overview of the most suitable areas (Natura 2000 Gebieden. LVVN, retrieved on 5-9-2025)

	Area	Province(s)	Natura 2000 designation	Description
1	Onlanden and Leekstermeergebied	Groningen and Drenthe	Only included in Birds Directive	Two wetland areas, characterized by open water bodies, peat bogs and narrow canals. There is a high vegetation cover with wide reed beds.
2	Weerribben-Wieden National Park	Overijssel	Whole area is included in Habitats Directive	Two connected areas that together form one of the largest wetlands in the Netherlands with a high variety of wetland vegetation. Large parts of the area are inaccessible to the public. This area was the main release site for the reintroduction of the otter.
3	Nieuwkoopse plassen and peat meadow areas to the south	Zuid-Holland	Nieuwkoopse plassen is included in Habitats Directive	This area is similar to nr 5. In addition to lakes and many watercourses, this area is mainly characterized by extensive reed beds.
4	Lowland peat complex north of Amsterdam	Noord-Holland	Many small areas, some of which are included in the Habitats Directive.	The area is characterized by natural meadows and narrow watercourses. It includes many important meadow bird reserves.
5	Oostelijke Vechtplassen and surrounding area	Noord-Holland and Utrecht	Most of the area is included in the Habitats Directive	This area features large lakes and inaccessible peatlands. It includes the Vecht river, which flows north towards the IJsselmeer. In large parts of the area there is high recreational pressure.
Other potentially interesting areas				
A	Drentsche Aa National Park and Zuidlaardermeergebied	Drenthe and Groningen	Only Drentsche Aa included in Habitats Directive	The Drentsche Aa is a brook valley that meanders through heathlands, wetlands and forests. Nearby, the Zuidlaardermeer is a large lake surrounded by reed beds and wet meadows.
B	Biesbosch National Park	Noord-Brabant	Whole area included in Habitats Directive	A vast freshwater tidal wetland, which is formed by the confluence of the Rhine and Meuse rivers. It is a dynamic ecosystem that is almost completely forested.
C	Oostvaardersplassen National Park	Flevoland	Only included in Birds Directive	This man-made marsh area is characterized by a high density of large herbivores. It is almost completely inaccessible for people.

tures of American mink and western polecat (on average 125 and 238 per year in the period 2007-2010) (LCCM 2011). It is therefore very likely that these traps will also pose a threat to the European mink. As already mentioned by Lange et al. (2022), the aim is to push the muskrat back to the Dutch-German border by 2034. In some regions, muskrats are effectively controlled, leading to a gradual reduction in trapping efforts. In the western lowland peat areas there is however still a very high density of muskrats and therefore also a high trapping intensity.

The Onlanden and Leekstermeergebied (1 in Figure 2) stand out as the highest-scoring region overall, making it a promising candidate for reintroduction. The area is however relatively narrow and it is only included in the Birds Directive, which makes it less suitable as currently no additional measures are obliged to be taken for the European mink after release. The Weerribben-Wieden (2) also scores very high, while also being larger and part of the Habitats Directive. Because this area served as the main release site for the reintroduction of the otter, otter-specific infrastructure has been installed across the area, like safe passages underneath roads. European mink have
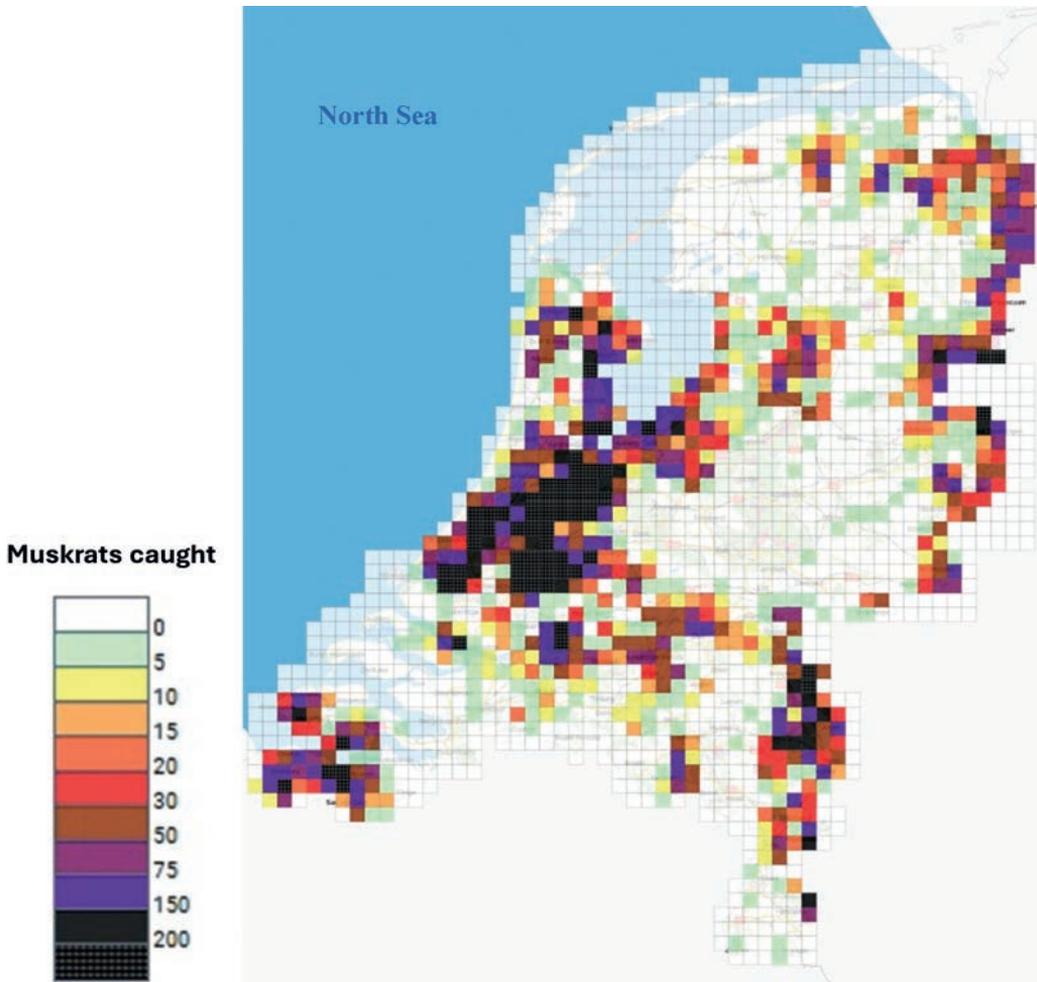
Figure 3. Total number of muskrats (*Ondatra zibethicus*) trapped per 5 x 5 km² in 2024. *Source*: Dolf Moerkens, Unie van Waterschappen.

also been found to use such passages (Dr. Tiit Maran, personal communication). As a result, these developments likely make the Weerribben-Wieden a particularly favourable site for a European mink reintroduction.

The Nieuwkoopse plassen (3) and Oostelijke Vechtplassen (5) both score well, although they are relatively fragmented and likely experience high human pressure from recreational activities and infrastructure such as roads. Notably, these areas suffer from a very high abundance of American crayfish. The European mink would therefore be a wel-

come crayfish predator here. On the other hand, these areas are also characterized by a high muskrat trapping intensity (Figure 3). Since European mink are also susceptible for these traps, these areas may currently not be a good option. However, as muskrats are being pushed back to the German border (Lange et al 2022), the suitability of these areas may increase over time.

Another high scoring area is the lowland peat complex north of Amsterdam (4). This area however includes many important reserves for meadow birds (Sierdsema et al.

2017), which are potential prey for the European mink. Although birds constituted a small part of the European mink diet in foreign studies (Palazón et al. 2004, Sidorovich et al. 2010), it is difficult to translate this to the Dutch situation and therefore the area may be unfavourable, also because it may not provide enough vegetation cover for the European mink. Lastly, the area is very isolated, making it less suitable for a reintroduction.

Some areas, although not ranked in the top five of the model, are still worth highlighting. First of all, the Drentsche Aa and Zuidlaardermeergebied (A in Figure 2) appear very suitable, especially as it is interconnected with area 1. Another potentially suitable area is the Biesbosch (B), one of the largest and most undisturbed wetland areas in the Netherlands. However, as a river delta it is relatively polluted (Rozema et al. 2008) and the area is also surrounded by urban areas and intensive agriculture. Last of all, the Oostvaardersplassen (C) could be an interesting option. It is one of the smaller areas, but it could serve as an important connection between the northern and western wetlands in the Netherlands.

When comparing the most suitable areas in the model to the current range of the European mink, the Danube delta seems to be most resembling, as this is a wetland dominated by dense vegetation like reed beds. Other areas, including the reintroduction sites in Estonia and Germany, are generally drier, indicating that the areas in the Netherlands could be more suitable. In the feasibility study by Lange et al. (2022), it is argued that the Weerribben-Wieden is probably the best release site, with the Biesbosch and lowland peat area in Zuid-Holland as other contenders. Our results confirm the suitability of these areas, but indicate that the Biesbosch may be too isolated. Some other areas are likely more suitable, like the wetlands on the Groningen-Drenthe border.

Overall, we think the rule-based habitat suitability model was a good choice for this study. That said, there are some limitations that must be addressed. First of all, because the model was based on shoreline density, the suitability of riparian areas without many shorelines like rivers, brooks and lakes may have been underestimated. We tried to better incorporate rivers with natural floodplains by including Natura 2000 and NNN (Nature Network the Netherlands) areas into the land use map as naturally managed agricultural land. Nonetheless, rivers still seemed to be relatively unsuitable, probably due to the low shoreline length. Additionally, some meadow bird areas were classified as highly suitable because they are also categorized as naturally managed agricultural land. This classification is questionable, as these areas generally lack sufficient vegetation cover for the European mink.

Importantly, the output map shows the relative suitability (i.e. which areas are the most suitable), instead of absolute suitability (i.e. is the area suitable or not). It was impossible to create an absolute suitability map, because this requires thresholds for suitability (e.g. how many roads per km^2 do European mink tolerate), which are unknown for the European mink. This means that we cannot say for certain that the Netherlands is suitable for the European mink, but we think it is very likely. Even if the thresholds were known, there would still be uncertainty simply because there are many factors involved that determine the success or failure of a reintroduction, and it is impossible to predict these. For better suitability estimates, a more rigorous model could be used, like a Maxent model based on proxy species like American mink, western polecat and otter (Barata et al. 2024). In addition, a least-cost path analysis can be carried out to better estimate the connectivity between suitable areas.

Conclusion

According to our habitat suitability analysis, the Netherlands likely provides several areas of highly suitable habitat for the European mink. Particularly promising regions in the

north include the Weerribben-Wieden and the Onlanden–Leekstermeer area, although the latter is not designated under the Habitats Directive. Due to their relative proximity to each other these areas are probably the most suitable for establishing a metapopulation, though fragmentation remains an important issue. The lowland peat areas in the west of the country with an abundance of American crayfish could also be good options. However, these areas are even more fragmented, have a high muskrat trapping intensity and a higher human presence. We recommend further investigation into the potential release sites, to (1) examine habitat characteristics in greater detail and identify area-specific ecological bottlenecks, (2) estimate the population size the areas can support, (3) assess the connectivity between areas, and (4) get a grip on the local political and societal dynamics that will play an important role in the success of the reintroduction.

Due to its long absence in the Netherlands, the European mink has become a relatively unfamiliar species. As such, it has received little attention, despite its critical conservation status. The recent disappearance of American mink in the Netherlands presents a unique opportunity to bring back a critically endangered species. This study can serve as a stepping stone by providing insights into the suitability of the Netherlands for a reintroduction of the European mink. In doing so, the study supports the research and conservation of a mammal that may sooner or later reclaim its place in the Dutch landscape. This is not only a crucial step for advancing its reintroduction in the Netherlands, but may also serve as a framework for similar reintroduction efforts in other countries.

References

Barata, I.M., V.M. Uhlig, L.G. Cortês, F. Fath & R.A. Griffiths 2024. Overcoming the lack of distribution data for rangerestricted habitat specialist frogs. Austral Ecology 49 (5): e13522. https://doi.org/10.1111/aec.13522

Borgå, K. 2013. Ecotoxicology: Bioaccumulation. In: Reference Module in Earth Systems and Environmental Sciences. Elsevier, Amsterdam, the Netherlands. https://doi.org/10.1016/B978-0-12-409548-9.00765-X

Broekhuizen, S. & E.M. de Ruiter-Dijkman 1988. Otters *Lutra lutra* met PCB's: de zeehondjes van het zoete water? Lutra 31: 68-78.

Danilov, P.I. & I.L. Tumanov 1976. The ecology of the European and American mink in the northwest of the USSR. In: E.V. Ivanter (ed.). Ecology of birds and mammals in the northwest of the USSR: 118–143. Institute of Biology of the Karelian Research Centre of the Russian Academy of Sciences, Petrozavodsk, Russia. [In Russian]

de Groot, G.A., W. van 't Westende, D.R. Lammertsma, F. Warmer, H.A.H.J. Jansman & M. Laar 2023. Status van de Nederlandse otterpopulatie in 2022: nieuwe inzichten in genetische uitwisseling, mortaliteit en verkeerssterfte. Wageningen Environmental Research, Wageningen, the Netherlands.

Dekker, J.J.A. & T. Hofmeester 2014. The status of the American mink (*Neovison vison*) in the Netherlands. Lutra 57 (1): 5-15.

Fournier, P., C. Maizeret, C. Fournier Chambrillon, N. Ilbert, S. Aulagnier & F. Spitz 2008. Spatial behaviour of European mink (*Mustela lutreola*) and polecat (*Mustela putorius*) in southwestern France. Mammal Research 53 (4): 343-354. https://doi.org/10.1007/BF03195195

Garin, I., J.A. Aihartza, I. Zuberogoitia & J. Zabala Albizua 2002. Activity pattern of European mink (*Mustela lutreola*) in southwestern Europe. European Journal of Wildlife Research 48: 102–106. https://doi.org/10.1007/BF02193548

Goicolea, T., R.L. Lewison, M.C. Mateo Sánchez & M.K.

Jennings 2022. Dynamic habitat suitability and connectivity analyses to inform management of an invasive species and conservation of its native competitor. https://doi.org/10.21203/rs.3.rs-1785503/v1

Gwynn, V. & E. Symeonakis 2022. Rule based habitat suitability modelling for the reintroduction of the grey wolf (*Canis lupus*) in Scotland. PLoS ONE 17 (10): e0265293. https://doi.org/10.1371/journal.pone.0265293

Harrington, L.A. & T. Maran 2024. European Mink *Mustela lutreola* (Linnaeus, 1761). In: K. Hackländer & F.E. Zachos (eds). Handbook of the Mammals of Europe. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-65038-8_135-1

Hirzel, A.H. & G. Le Lay 2008. Habitat suitability modelling and niche theory. Journal of Applied Ecology 45 (5): 1372-1381. https://doi.org/10.1111/j.1365-2664.2008.01524.x

Hunter-Ayad, J., R. Ohlemüller, M.R. Recio & P.J. Seddon 2020. Reintroduction modelling: A guide to choosing and combining models for species reintroductions. Journal of Applied Ecology 57 (7): 1233-1243. https://doi.org/10.1111/1365-2664.13629

La Haye, M. & R. Janssen 2025. The closure of mink farms in the Netherlands: a unique opportunity for European mink. Lutra 68 (1-2): 57-61.

LCCM (Landelijke Coördinatiecommissie Muskusrattenbestrijding) 2011. Bijvangsten muskusrattenbestrijding: trends, oorzaken en maatregelen. Definitief rapport. LCCM.

Lange, P., G. Lelieveld & M. La Haye 2022. A feasibility study on the reintroduction of the European mink (*Mustela lutreola*) in the Netherlands. Dutch Mammal Society, Nijmegen, the Netherlands.

Lodé, T. 2002. An endangered species as indicator of freshwater quality: Fractal diagnosis of fragmentation within a European mink (*Mustela lutreola*) population. Fundamental and Applied Limnology 155 (1): 163–176. https://doi.org/10.1127/archiv-hydrobiol/155/2002/163

Lodé, T., J.-P. Cormier & D. Le Jacques 2001. Decline in endangered species as an indication of anthropic pressures: The case of European mink (*Mustela lutreola*) western population. Environmental Management 28 (6): 727–735. https://doi.org/10.1007/s002670010257

Maran, T. 2007. Conservation biology of the European mink (*Mustela lutreola*) (Linnaeus 1761): Decline and causes of extinction. PhD thesis, Tallinn University, Estonia.

Maran, T. & H. Henttonen 1995. Why is the European mink (*Mustela lutreola*) disappearing? A review of the process and hypotheses. Annales Zoologici Fennici 32 (1): 47–54.

Mitchell-Jones, A.J., G. Amori, B. Kryštufek, F. Marnell, S. Miteva, A. Sallay Moşoi, L. Schley, J. Thissen & V. Vohralík (eds) (in press). Atlas of European Mammals (2nd ed.). CRC Press, Boca Raton, USA.

Mollot, G., J.H. Pantel & T.N. Romanuk 2017. Chapter Two – The effects of invasive species on the decline in species richness: A global meta analysis. In: D.A. Bohan, A.J. Dumbrell & F. Massol (eds). Advances in Ecological Research 56: 61–83. Academic Press, Cambridge, Massachusetts, USA.

Nationaal Dashboard Biodiversiteit 2025. Het Nationaal Dashboard Biodiversiteit. https://dashboard-biodiversiteit.nl/

Ortiz-Jiménez, L., C. Iglesias Merchan & I. Barja 2021. Behavioral responses of the European mink in the face of different threats: Conspecific competitors, predators, and anthropic disturbances. Scientific Reports 11 (1): 8266. https://doi.org/10.1038/s41598-021-87905-5

Palazón, S., J. Ruiz Olmo & J. Gosàlbez 2004. Diet of European mink (*Mustela lutreola*) in northern Spain. Mammalia 68 (2–3): 159-165. https://doi.org/10.1515/mamm.2004.016

Palazón, S., Y. Melero, A. Gómez, J.L. de Luzuriaga, M. Podra & J. Gosàlbez 2012. Causes and patterns of human induced mortality in the critically endangered European mink (*Mustela lutreola*) in Spain. Oryx 46 (4): 614-616. https://doi.org/10.1017/S0030605312000920

Palomares, F., J.V. López-Bao, G. Telletxea, J.C. Ceña, P. Fournier, G. Giralda & F. Urra 2017. Activity and home range in a recently widespread European mink population in western Europe. European Journal of Wildlife Research 63 (5): 78. https://doi.org/10.1007/s10344-017-1135-0

Peters, E., I. Brinkmann, F. Krueger, S. Zwirlein & I. Klaumann 2009. Reintroduction of the European mink (*Mustela lutreola*) in Saarland, Germany: Preliminary data on the use of space and activ-

ity as revealed by radio tracking and live trapping. Endangered Species Research 10: 305-320. https://doi.org/10.3354/esr00180

Phillips, S.J., M. Dudík & R.E. Schapire 2004. A maximum entropy approach to species distribution modeling. In: Twenty-First International Conference on Machine Learning (ICML '04): 83. https://doi.org/10.1145/1015330.1015412

Põdra, M. & A. Gómez 2018. Rapid expansion of the American mink poses a serious threat to the European mink in Spain. Mammalia 82 (6): 580-588. https://doi.org/10.1515/mammalia-2017-0013

Põdra, M., L.A. Harrington, M. Díez-León & T. Maran 2025. *Mustela lutreola* (Europe assessment). The IUCN Red List of Threatened Species 2025: T14018A215858306. https://dx.doi.org/10.2305/IUCN.UK.2025-1.RLTS.T14018A215858306.en

Rozema, J., M.J.M. Notten, R.A. Aerts, C.A.M. van Gestel, P.H.F. Hobbelen & T.H.M. Hamers 2008. Do high levels of diffuse and chronic metal pollution in sediments of Rhine and Meuse floodplains affect the structure and functioning of terrestrial ecosystems? Science of The Total Environment 406 (3): 443-448. https://doi.org/10.1016/j.scitotenv.2008.06.055

Santulli, G., S. Palazón, Y. Melero, J. Gosálbez & X. Lambin 2014. Multi-season occupancy analysis reveals large-scale competitive exclusion of the critically endangered European mink by the invasive non-native American mink in Spain. Biological Conservation 176: 21–29. https://doi.org/10.1016/j.biocon.2014.05.002

Sidorovich, V., A. Polozov & A. Zalewski 2010. Food niche variation of European and American mink during the American mink invasion in northeastern Belarus. Biological Invasions 12: 2207–2217. https://doi.org/10.1007/s10530-009-9631-0

van Bree, P.J.H. 1961. On the remains of some Carnivora found in a prehistoric site at Vlaardingen, the Netherlands. Beaufortia, 8(91), 109–118.

van Bree, P.J.H. 1976. Over de resten van twee uit Nederland afkomstige nertsen, *Mustela lutreola* (Linnaeus, 1761). Natuurhistorisch Maandblad 65 (4): 66-70.

Youngman, P.M. 1982. Distribution and systematics of the European Mink *Mustela lutreola* Linnaeus 1761. Acta Zoologica Fennica 166: 1-48.

Zabala, J. & I. Zuberogoitia 2003. Habitat use of male European mink (*Mustela lutreola*) during the activity period in south-western Europe. Zeitschrift für Jagdwissenschaft 49 (1): 77-81. https://doi.org/10.1007/BF02192015

Zabala, J., I. Zuberogoitia, I. Garin & J. Aihartza 2003. Landscape features in the habitat selection of European mink (*Mustela lutreola*) in south-western Europe. Journal of Zoology 260 (4): 415-421. https://doi.org/10.1017/S0952836903003881

Zabala, J., I. Zuberogoitia & J.A. Martínez-Climent 2006. Factors affecting occupancy by the European mink (*Mustela lutreola*) in south-western Europe. Mammalia 70 (3–4): 193-201. https://doi.org/10.1515/MAMM.2006.051

Zuberogoitia, I., H. Zalewska, J. Zabala & A. Zalewski 2013. The impact of river fragmentation on the population persistence of native and alien mink: An ecological trap for the endangered European mink. Biodiversity and Conservation 22 (1): 169-186. https://doi.org/10.1007/s10531-012-0410-3

Samenvatting

Habitatgeschiktheid voor de herintroductie van de Europese nerts (*Mustela lutreola*) in Nederland

Als een van de meest bedreigde zoogdieren in Europa heeft de Europese nerts (*Mustela lutreola*) dringend beschermingsmaatregelen nodig om de soort van uitsterven te behoeden. Een van de grootste bedreigingen is de invasieve Amerikaanse nerts (*Neogale vison*), die in Europa wijdverspreid is en hier de Europese nerts heeft verdreven. In Nederland is de Amerikaanse nerts in 2025 echter vrijwel verdwenen, wat kansen biedt voor een herintroductie van de Europese nerts. Het doel van dit onderzoek was om de meest geschikte gebieden voor een herintroductie in Nederland in kaart te brengen. Hiervoor is een *rule-based* habitatgeschiktheidsmodel ontwikkeld in de *Suitability modeler* tool in ArcGIS Pro. Het model is gebaseerd op de belangrijkste habitateisen van de Europese nerts: natuurlijk terrein

met voldoende beschutting, aanwezigheid van water, weinig wegen en afwezigheid van mensen. Volgens het model lijkt Nederland over een aanzienlijk aantal geschikte gebieden te beschikken, hoewel de geschiktheid van gebieden varieert door factoren zoals versnippering en isolatie. Ook de bestrijding van muskusratten speelt een rol, vooral in het westen van Nederland, omdat nertsen kwetsbaar zijn voor de vallen die hiervoor gebruikt worden. De moerasgebieden in Noord-Nederland komen naar voren als de meest geschikte herintroductiegebieden, met de Weerribben-Wieden en de Onlanden/Leekstermeergebied als best-scorende gebieden. Ook de Oostelijke Vechtplassen en Nieuwkoopse plassen lijken geschikt, met als bijkomend voordeel de hoge dichtheden van Amerikaanse rivierkreeft (*Procambarus clarkii* en *Procambarus acutus*), waarop de nerts kan prederen. Versnippering en intensieve muskusratbestrijding vormen hier echter nog uitdagingen. De Biesbosch, Drentsche Aa en Oostvaardersplassen zijn potentieel ook interessante gebieden, maar scoren minder hoog in het model. Vervolgonderzoek wordt aanbevolen om (1) gebiedseigenschappen verder in kaart te brengen, (2) connectiviteit tussen gebieden te bepalen en (3) inzicht te krijgen in de lokale politieke en maatschappelijke factoren die belangrijk zijn voor een succesvolle herintroductie. Voor zover wij weten, is dit de eerste habitatgeschiktheidsstudie voor de Europese nerts in Europa. De bevindingen kunnen niet alleen bijdragen aan de ontwikkeling van een herintroductieplan in Nederland, maar ook als voorbeeld dienen voor vergelijkbare studies in andere landen.