European Wildcats in Limburg

A study on presence, suitable habitats and potential corridors

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Course: Extended master's thesis (45 EC)
Course code: GEO4-2321 & GEO4-2322

Summary

The European wildcat (Felis silvestris silvestris) recently returned to forests in Limburg after being locally extinct in the Netherlands for more than a thousand years. Wildcats are beneficial for biodiversity because they can function as an umbrella and flagship species in conservation efforts. To facilitate a stable metapopulation of wildcats in the Netherlands, more knowledge is needed on wildcat presence, habitat quality and corridors. In this study, I determined wildcat presence with a camera trap study in forests in Zuid-Limburg. I found six wildcats in Vijlenerbos, and one each in Savelsbos, Groote Bosch and De Molt in the Bovenste Bosketen. These are the first confirmed sightings of wildcats in Savelsbos and Groote Bosch. Additionally, I applied an existing habitat suitability model to analyse suitable wildcat home ranges in the province of Limburg. I found that habitat patches are suboptimal in Zuid-Limburg, even though it is the only region in the Netherlands where wildcats are currently present. The most important reasons for the low habitat quality is that forest patches are either too small or too close to villages. Using a least-cost path analysis, I identified a connection network for forests in Zuid-Limburg and the major obstacles where green corridors can be established to improve the connectivity of small forest patches in Zuid-Limburg. With these green corridors, there are more opportunities for wildcat dispersion, and forests in Zuid-Limburg can hold a wildcat subpopulation. In Noord-Limburg, I identified 13 suitable home ranges with a total area of 276 km^2, which can hold an accumulative subpopulation size of 76-137 wildcats. An analysis of the least-cost pathways through Limburg revealed that villages and roads in Zuid-Limburg act as major obstacles for wildcat dispersal. The most feasible routes to the potential home ranges in Noord-Limburg might through Germany and Belgium. Therefore, international cooperation is of vital importance when designing a corridor plan for wildcats and other species in the Netherlands.

This study was done as part of an internship at ARK Nature. The project was financially realized with the help of the province of Limburg. The forests in the camera trap study area are managed by Staatsbosbeheer and Stichting Het Limburgs Landschap.

1. Introduction

The return of the wildcat

The European wildcat (*Felis silvestris silvestris*, Schreber 1777) recently returned to the Netherlands after an absence of more than a thousand years (Meertens & Kuipers, 2018). The wildcat is a medium-sized predator that was once native to the Netherlands but went locally extinct at the end of the roman period (circa 300 AD) as a result of habitat destruction and hunting (Canters et al., 2005). Near the start of this century, evidence of a possible comeback emerged in Zuid-Limburg, where a dead cat was found along the road and a living one appeared on a camera trap (Meertens & Kuipers, 2018). In the last 10 years, wildcat sightings became more frequent in the Netherlands, with 9 adult and 5 juvenile individuals appearing on camera traps in Zuid-Limburg in 2017 alone (Kuipers, 2016, 2017). Meertens & Kuipers (2018) estimate a population of between 10 and 30 individuals in 2017. These wildcats likely entered the Netherlands from the Eifel forest range in Germany, where population sizes have also increased in recent years (Bund für Umwelt und Naturschutz Deutschland, 2020).

The return of wildcats to Dutch ecosystems contributes positively to biodiversity in the Netherlands because of two main reasons. First, wildcats can function as an umbrella species for the conservation of other species. The presence of wildcats indicates that the ecosystem fulfils a set of habitat requirements that other species also benefit from (Meertens & Kuipers, 2018). Wildcats prefer to live in mixed forests with cover, sufficient numbers of rodents and other prey, and limited human structures and activity (Janssen et al., 2016; Klar et al., 2008). These conditions are also beneficial for other native predators like foxes, badgers, and martens (Brouns, 2015; Bund für Umwelt und Naturschutz Deutschland, 2011). Furthermore, wildcats can be an effective flagship species in public campaigns for conservation because of humans' affinity with domestic cats (Franck, 2010).

Threats for cats

The most important obstacle that keeps wildcats from recolonizing Dutch ecosystems is habitat fragmentation (Birlenbach et al., 2009; Brouns, 2015). The fragmentation of wildcat habitats poses risks for the long-term survival of the species, because smaller populations are more susceptible to catastrophic events, and to genetic threats such as inbreeding, genetic drift, and hybridization with the domestic cat *Felis Catus* (Birlenbach et al., 2009). Hybridization can occur when wildcat populations are small and isolated, and their territories are near areas with high domestic cat densities like villages or agricultural areas (Hertwig et al., 2009).

The preferred habitat of European wildcats mainly consists of large areas of forests and neighbouring grasslands (Janssen et al., 2016; Klar et al., 2008). Land use change from forests and natural grasslands to intensively grazed agricultural landscapes and villages was likely one of the main reasons for the local extinction in the Netherlands (Canters et al., 2005), and wildcats still avoid these human-dominated areas (Janssen et al., 2016; Klar et al., 2008). However, there are no continuous forest patches large enough to hold stable wildcat populations (Hötzel et al., 2007) in Zuid-Limburg or elsewhere in the Netherlands. A solution to this problem is to connect smaller forest patches with green corridors, which allows for wildcat dispersal between patches (Bund für Umwelt und Naturschutz Deutschland, 2009). If these patches are also connected to habitat patches in Belgium and Germany, forest patches in the Netherlands can hold small wildcat subpopulations which can be part of a cross-border wildcat metapopulation.

Putting the wildcat back on track

An example of a wildcat conservation plan that focuses on connecting forest patches with corridors is the Wildkatzenwegenplan by The *Friends of the Earth Germany (BUND)* (2009). They designed a spatial planning of green corridors to connect forest patches in Germany where wildcats are currently present to other forest patches which are suitable as wildcat habitats, but are currently uninhabited. Since 2010, they realized many of these corridors, which allowed for dispersal of wildcats and other species between habitat patches. As a result, wildcats in Germany have returned to forests where they have long been absent, the number and size of subpopulations have increased (Bund für Umwelt und Naturschutz Deutschland, 2020), effectively forming a metapopulation (Mattucci et al., 2016) that is better suited to withstand catastrophic events and genetic threats (Akçakaya et al., 2007).

ARK Nature (2021) is currently running a comparable project to facilitate wildcat subpopulations in the Netherlands (Brouns, 2015). To identify the presence of wildcats, ARK researchers conducted several studies with camera traps in various forests in Zuid-Limburg (see figure 1). They found between 8 and 11 adult wildcats in Vijlenerbos (Brouns, 2015; Janssen et al., 2016; Kuipers, 2017), and 3 adults in the forest chain of Bovenste Bos, Onderste Bos, Schweibergerbos and De Molt (Kuipers, 2016, 2017, 2019), to be further addressed as Bovenste Bosketen. In other areas, sightings were rare, with four lone cats in the Gerendal, Platte Bosch, Noordal and a small forest patch between Wahwiller and Nijswiller (Janssen & Mulder, 2013; Kuipers, 2017, 2019), and no sightings in other studied forests in Zuid-Limburg.

Research questions

While there have been frequent studies on the presence of wildcats in Zuid-Limburg in the past ten years, less is known on the quality of uninhabited potential wildcat habitat patches and corridor usage in Limburg. Knowledge on habitat and corridor quality and usage is instrumental to design a conservation plan that allows wildcats to recolonize habitat patches in the Netherlands. In collaboration with ARK Nature, I therefore performed a study with three main goals: First, to update our knowledge of the current size and spread of the wildcat population in Zuid-Limburg. Second, to analyse the quality and suitability of potential wildcat habitat patches in Limburg. The third goal was to analyse corridors between suitable habitat patches. I aimed to achieve these goals by answering the following research questions:

1) What is the current state of the population of the European wildcat in forests in Zuid-Limburg?
2) Which areas in Limburg are most suitable as potential wildcat habitats?
3) What are potential routes that wildcats can use to transition between current and potential habitats for wildcats in Limburg?

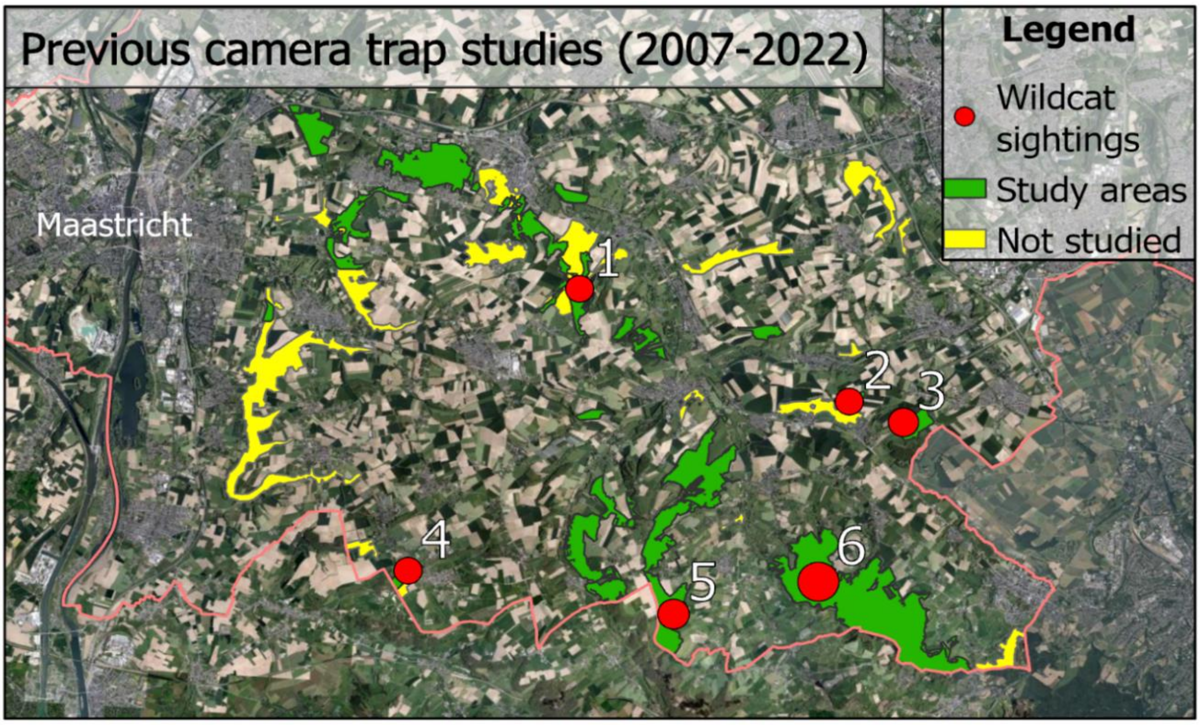
For RQ1, I conducted a camera trap study in 12 forests in Zuid-Limburg in the winter of 2022. For RQ2, I performed a spatial analysis in ArcGIS PRO with an existing habitat suitability model (Klar et al., 2008) to identify the areas that are most suitable as wildcat habitats in the entire province of Limburg. For RQ3, I used the results from the camera trap study and the suitability model to calculate the lowest cost paths from source patches with wildcat presence to destination patches of potential wildcat habitats in Limburg. In this paper, I first present relevant theory on the three research questions and the context of this study. Then, I expand on the methods used for the camera trap study and the spatial analysis. Afterwards, I present the results of this study and use them to answer the research questions, and finally I discuss how they relate to the existing literature on wildcat habitat- and corridor usage.

2. Theoretical framework

2.1 Wildcats in Zuid-Limburg

Historical sightings

Canters et al. (2005) analysed the history and validity of wildcat sightings in the Netherlands up until 2004. They concluded that only three wildcats were reported in the period from 1990 to 2004, of which one was in Zuid-Limburg. Later, Mulder (2007) spotted a cat on a camera trap in Bovenste Bos with phenotypical wildcat characteristics. Additional studies with camera traps followed, although the only sighting between 2007 and 2013 in Limburg was of one wildcat in Noordal in 2013 (Janssen & Mulder, 2012, 2013). From that point onwards, wildcat sightings became more frequent (see figure 1). Brouns (2015) spotted ten cats on camera traps in 2014. Five of these cats were radio-tracked (Janssen et al., 2016), which revealed that two cats had territories which expanded into the neighbouring forest Aachenerwald in Germany (Janssen et al., 2016). Kuipers (2017) observed six different wildcats on camera in 2017 in Vijlenerbos. Two of these cats gave birth to kittens in 2017, with one nest consisting of five kittens, and the other litter size was unknown.



●	Location	Kuipers (2019)	Kuipers (2017)	Other studies
1	Gerendal	1	-	-
2	Kloofbos	-	1	-
3	Platte Bosch	1	0	-
4	Noordal	-	-	1 (Janssen & Mulder, 2013)
5	Bovenste Bosketen	1	2	1 (Kuipers, 2016). 1 (Mulder, 2007)
6	Vijlenerbos	-	6	10 (Brouns, 2015)

Figure 1: Number of adult wildcats observed in previous studies with camera traps in Zuid-Limburg. Forest areas under the management of Staatsbosbeheer (2021) or Limburgs Landschap (2021) which have not yet been subject to a camera trap study are displayed in yellow.

While the presence of wildcats in Vijlenerbos stabilized in the last 8 years, other forests in Zuid-Limburg did not have consistent sightings of wildcats that could indicate their presence in a forest over a longer period (Meertens & Kuiper, 2018). Kuipers (2017) identified one male and one female wildcat in Bovenste Bosketen, and a wildcat in a small forest patch between Wahlwiller and Nijswiller (Kloofbos in figure 1). Two years later, Kuipers (2019) performed another study with the same methods. She found one cat on camera in Gerendal and one in Platte Bosch. The latter had a similar appearance to the cat observed in Kloofbos, but the quality of the video footage was not high enough to say for certain that it was the same cat. She studied Bovenste Bosketen again, but the cats observed in 2017 did not return on camera in 2019. This suggests that they may have died or were not present anymore in the forest during that period. However, cats will not always visit camera traps even with lures, thus it is also possible that they were still present in the forest at the time.

Hybridization

An important factor to consider when studying wildcat populations is hybridization with the domestic cat. Hybridization can be a threat to genetic diversity if a domestic species swamps its wild counterpart (Tiesmeyer et al., 2020). As a result of hybridization, many wildcats have some degree of domestic cat DNA in them. In extreme cases, like in the Scottish and Hungarian wildcat populations, the genetic integrity of wildcats is seriously compromised to the point where almost all wild-living cats have a combination of wild- and domestic cat DNA (Hertwig et al., 2009; Mattucci et al., 2016).

European wildcat populations are divided in five main biogeographic regions (see figure 2) based on genetic clusters (Mattucci et al., 2016). The influx of wildcats in the Netherlands likely originates from wildcat populations in the Eifel Forest range and the Ardennes (Meertens & Kuipers, 2018), which are part of the Central European group. The rate of hybridization with domestic cats is generally low in this group (3-5%), and there is no evidence of significant hybridization events (Tiesmeyer et al., 2020). The other main biogeographic groups also have low hybridization rates, but there are subpopulations within the main groups where regionally high hybridization rates have been reported (Hertwig et al., 2009; Tiesmeyer et al., 2020). A theory used to explain these regional differences is that hybridization is more likely to occur when there are more opportunities for encounters between wildcats and domestic cats. Domestic cats usually live in or near villages and agricultural areas, while wildcats avoid these areas and prefer forests and forest edges as habitats (Janssen et al., 2016; Klar et al., 2009). When wildcat and domestic cat habitats are small and fragmented, there are more edge regions between habitats, and the chance of encounters and hybridization increases (Tiesmeyer et al., 2020). The low hybridization rate in the Central European cluster is likely a result of a relatively low human population density in combination with a large network of connected areas which are suitable for wildcat settlement (Mattucci et al., 2016). However, this does not mean that there is no risk of hybridization in potential wildcat subpopulations in Zuid-Limburg, as population density is relatively high and forest patches are small.

Currently, there is not enough data on the occurrence of wildcats, hybrids and backcrosses in the Netherlands to draw conclusions on hybridization rates. Even though the number of wildcat sightings has increased in the last couple of years, genetic data of wild-living cats is still relatively scarce because the collection of genetic material often requires invasive methods such as cage trapping. For this reason, many researchers prefer to use camera traps in combination with lure or bait to obtain photographic data. Photos and videos can be analysed by looking at pelage markings to indicate subspecies by their phenotype with reasonable precision (Kitchener et al., 2005). I will further expand on pelage markings analysis in the methods section.

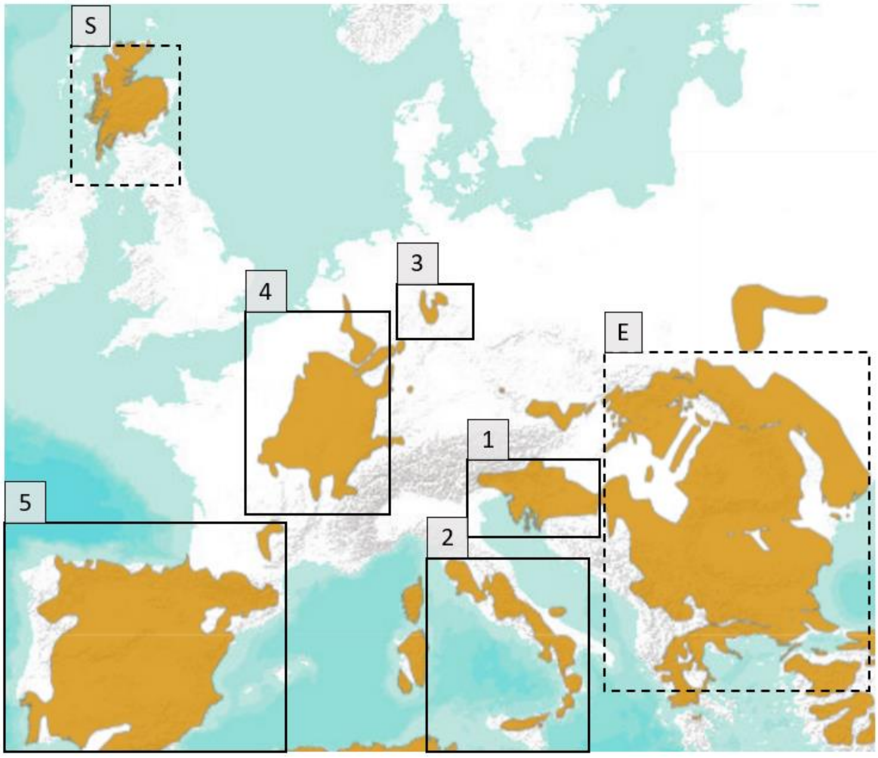


Figure 2: Geographic home ranges of European wildcats are displayed in orange. (Adapted from Yamaguchi et al. (2015)). The solid squares indicate the five main biogeographic groups of European wildcats identified by Mattucci et al. (2016). 1: Eastern and Dinaric Alps. 2: Italian Peninsula and Sicily. 3: Central Germany. 4: Central Europe. 5: Iberian Peninsula. The Scottish population (S) and Eastern European population (E) were not recognized as wildcat groups because they had high levels of hybridization or a lack of data.

2.2 Wildcat habitats

Habitat types

European wildcats are predominantly found in broad-leaved and mixed forests, but they have also been observed in maquis scrublands and along seacoasts in the Mediterranean populations, in riparian forests and marsh boundaries (Yamaguchi et al., 2015), and in agricultural landscapes if there is sufficient cover (Jerosch et al., 2016). Studies that use radio-tracked collar transmitters provide more detailed insight in habitat use. Klar et al. (2008) tracked 12 cats in the Eifel Mountain range to study which land use features influence wildcat habitat use. They found that wildcats mostly live in forests, with 75% of recorded radio locations being in forests for males and 91% for females. During the daytime, wildcats rest in places with cover such as dead wood structures or old badger setts, (Jerosch et al., 2010), while they move closer to meadows, forest edges or riparian areas during their activity hours in the night (Klar et al., 2008). The most likely reason for this is the abundance of rodents in grasslands, forest edges and riparian areas, which are their main prey (Franck, 2010; Nowell & Jackson, 1996). Furthermore, wildcats were less likely to be found within 900 metres from villages and 200 metres from roads and single houses (Klar et al., 2008). Janssen et al. (2016) conducted a similar study in Vijlenerbos with 5 tracked cats. They also found a preferred use of forest and grasslands, as well as an avoidance of human structures. Additionally, the cats in Vijlenerbos preferred ‘natural’ grasslands with a greater diversity of plants over intensively grazed grasslands with low biodiversity.

Habitat size

Furthermore, wildcats need large home ranges. Typically, males have larger home ranges than females (Janssen et al., 2016). Hötzel et al. (2007) found average home ranges of roughly 1200 ha for males and 400 ha for females in wildcat populations in the Eifel and north-western France. The three adult radio-tracked male cats of the Vijlenerbos had home ranges of 3426, 721 and 2071 ha, and the one adult female cat 166 ha (Janssen et al., 2016). In a study of wildcats in a more open landscape, Jerosch et al. (2016) reported average annual home ranges of 1189 ha for males and 285 ha for females.

However, territories can overlap (Janssen et al., 2016; Klar et al., 2008). Klar et al. (2012) estimate wildcat densities at 0.3 – 0.5 wildcats per km^2 in suitable habitat patches. If we apply this density to the Vijlenerbos (625 ha) in our study area, this means that there is room for 2 to 3 wildcats in the forest. The telemetry study from Janssen et al. (2016) had three wildcats which exclusively stayed in Vijlenerbos and two cats whose home ranges expanded into the Aachener Wald as well. Since there were an additional 5 cameras that appeared on camera traps in the study area in that period (Brouns, 2015), the density of 0.3 – 0.5 wildcats per km^2 might be a conservative estimate.

2.3 Corridors

Wildcats are adventurous animals with a high willingness to roam, especially males looking for a mate (Franck, 2010). Telemetry studies provide data on their preference within habitat patches, but there is less knowledge on what factors influence route selection between patches. However, it is generally accepted that wildcats prefer to traverse through green corridors with cover over more open landscapes (Brouns, 2015; Bund für Umwelt und Naturschutz Deutschland, 2009). The only major barriers that wildcats almost never cross are open water, highway junctions and villages (Klar et al., 2012). They show avoidance of highways to a lesser extent (Klar et al., 2009). When they do traverse highways or smaller roads, there are risks of collisions with cars, and roadkills are one of the main causes of death of wildcats in areas with many high-speed roads (Klar et al., 2009).

2.4 Context and conservation

Population dynamics

From the previous studies by ARK researchers, we can conclude that there is a stable presence of wildcats in Vijlenerbos since 2014, while cats only appeared occasionally in other forests and never in groups larger than 2. The disappearance from the two cats in Bovenste Bosketen between 2017 and 2019 and the suspected movement from the Kloofbos to Platte Bosch from one wildcat makes it likely that cats experience local (pseudo-)extinctions. A pseudo-extinction means that a patch became vacant not because of death, but because indidivuals emigrated (Elmhagen & Angerbjörn, 2001). Along with the fragmented nature of forest areas in Zuid-Limburg, this raises the question how metapopulation dynamics play a role in the wildcat populations in the forests in Zuid-Limburg and nearby areas across the Belgian and German borders. A metapopulation is essentially a population of subpopulations in a heterogenous environment (Akçakaya et al., 2007). These subpopulations are located in discrete habitat patches, separated by a matrix which individuals can traverse, but not breed in (Levins, 1969). Metapopulation theory applies to medium-sized carnivores like the wildcat when 1) there are discrete habitat patches large enough for breeding subpopulations, and 2) there are ecological processes on both local (i.e. population growth and extinctions) and metapopulational (i.e. migration and colonization) scales (Elmhagen & Angerbjörn, 2001; Hanski, 1999). Metapopulations can persist even when subpopulations are very small if dispersal between habitat patches is high enough to balance out local extinctions (Akçakaya et al., 2007; Hoopes & Harrison, 1998).

Other population dynamics with some aspects of metapopulational processes are non-equilibrium-, patchy-, sink-source-, and mainland-island populations. These dynamics mainly differ from metapopulations in their migration rates and habitat quality (Elmhagen & Angerbjörn, 2001). There is a non-equilibrium population when extinction rate exceeds migration rate. In this case, regional processes do not have a significant effect on the population network as subpopulations become isolated (Elmhagen & Angerbjörn, 2001). Non-equilibrium populations typically have low migration rates because dispersal through the matrix is hard, or the distance between the patches is too high (Hoopes & Harrison, 1998). On the other end of the spectrum of migration rate there are patchy populations. Here, migration rate between patches is so high that the network acts as one connected population, and processes on a local scale become irrelevant (Elmhagen & Angerbjörn, 2001). A classical metapopulation lies between the extremes of a non-equilibrium and a patchy population (Elmhagen & Angerbjörn, 2001). In a metapopulation there are local extinctions in habitats, which are balanced by the recolonization of patches through migration (Hanski, 1999).

When habitats differ in quality, there are source patches with positive growth rates, and sink patches with negative growth rates, which are dependent on immigration from source patches (Akçakaya et al., 2007). When the quality of the patch is linked to patch size, source-sink populations can be viewed as mainland-island populations. The smaller island populations are not necessarily situated on actual islands, but have a high risk of local extinctions because the patch is too small to host a breeding population. As a result, local growth rates in the 'island' patches are negative, and the island populations are reliant on migration from the larger 'mainland' populations where growth rates are positive (Hoopes & Harrison, 1998).

The results of this study can be used to determine which population dynamics are most relevant for wildcats in Limburg. The camera trap study and habitat analysis indicate if there are multiple habitat patches in Limburg which are suitable for breeding subpopulations, while the corridor analysis provides insight in the discreteness of the patches and how the corridors can facilitate traversal between patches. It is useful get an insight in the wildcat population dynamics in Limburg, because it has implications for conservation strategies (Akçakaya et al., 2007). Mainly, knowledge on population dynamics can be used to identify areas where habitat quality can be improved and corridors can be established.

Rewilding

A conservation approach that has gained traction in the last 30 years that combines the strengthening of corridors with the conservation of predators is rewilding. With this approach, conservationists want to allow natural processes to restore degraded landscapes, and improve and stabilize ecosystems (Rewilding Europe, 2022). The most important principles of the original concept of rewilding can be summarized with the three C's (Soulé & Noss, 1998):

1. Large, strictly protected **C**ores areas of landscape
2. **C**orridors between the cores
3. Large **C**arnivores or other keystone species

Simply put, keystone species are species that are vital to the functioning of ecosystems by interacting with their environment and other species in ways that are disproportionate to their population size. Large predators are often keystone species, because their removal would lead to significant changes on lower trophic levels in an ecosystem (Soulé & Noss, 1998). For example, a decrease in predator population size due to overhunting or habitat destruction can lead to an increase in herbivore population sizes, which in turn affects diversity and population size of primary producers. Therefore, rewilding efforts are often targeted at large carnivores or other keystone species by establishing large strictly protected core areas, and strong corridors between these areas (Soulé & Noss, 1998).

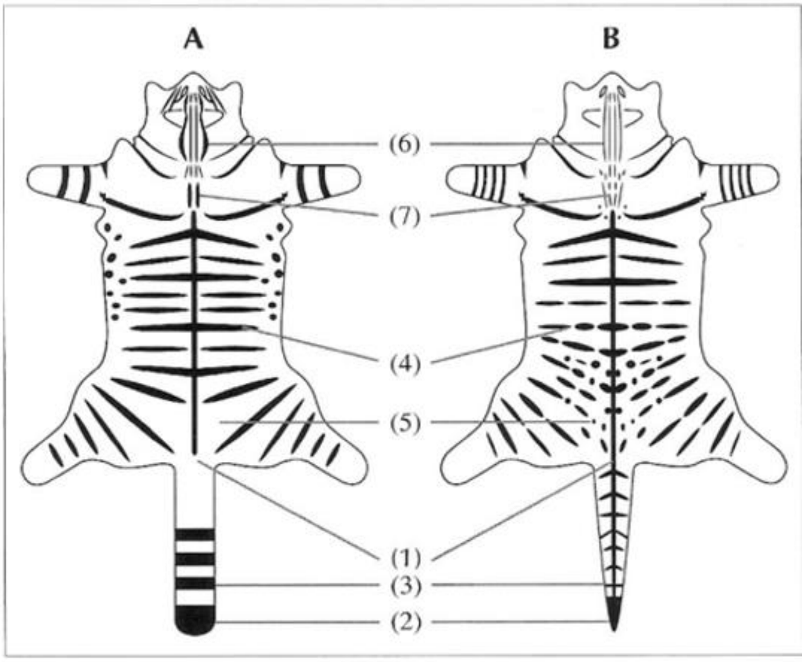
3. Methods

3.1 Study species

I use the wildcat taxonomy by Kitchener et al. (2017). The species is wildcat (*Felis silvestris),* and the subspecies is European wildcat *(Felis silvestris silvestris,* Schreber 1777*)*, which includes the Scottish population of European wildcats. The pelage marking analysis method which I used was developed for the Scottish population. Some authors identify the Scottish population as the distinct subspecies Scottish wildcat (*Felis silvestris Grampia)* but it is doubtful that the Scottish wildcat is distinct from the European population based on morphological, molecular and biogeographical criteria (Kitchener et al., 2017). Domestic cats, including feral cats, are classified as *Felis catus.*

Pelage marking analysis

European wildcats are similar in appearance to domestic tabby cats, but there are several characteristics in pelage markings that are typical for wildcats, while they are less likely to appear in domestic cats (Meertens & Kuipers, 2018). I distinguished between wildcats and domestic cats with the 7 Pelage Score (7PS) system by Kitchener et al. (2005). They identified seven differences in pelage markings between domestic- and wildcats which are the most indicative of their subspecies. Each of these markings is graded from 1 to 3 to create a 7PS as seen in figure 3 (Kitchener et al., 2005). A score of 1 indicates a typical domestic cat pelage characteristic, while a 3 indicates a typical wildcat characteristic, and a 2 is used for more doubtful markings. Therefore, cats can have a 7PS ranging from 7 (typical domestic cat) to 21 (typical wildcat). While the 7PS system was created by analysing wild-living cats from the Scottish population, it has also been used to identify wildcats in a Spanish wildcat population (Ballesteros Duperón et al., 2014). Therefore, it seems safe to assume that it can provide feasible indications of subspecies in the Netherlands as well. Kitchener et al. (2005) proposed two definitions to identify wildcats. A strict definition is that cat with a score of 19 or higher and no scores of 1 for any trait should be regarded as wildcats. I used the more lenient definition, which states that cats with scores of 2 or higher for every trait can be regarded as wildcats (WC). Other tabby cats were classified as domestic cats (DC). I did not try to identify hybrids or backcrosses by pelage marking. I performed all species identifications, pelage marking analyses and sketches myself to reduce differences in interpretation between different researchers.



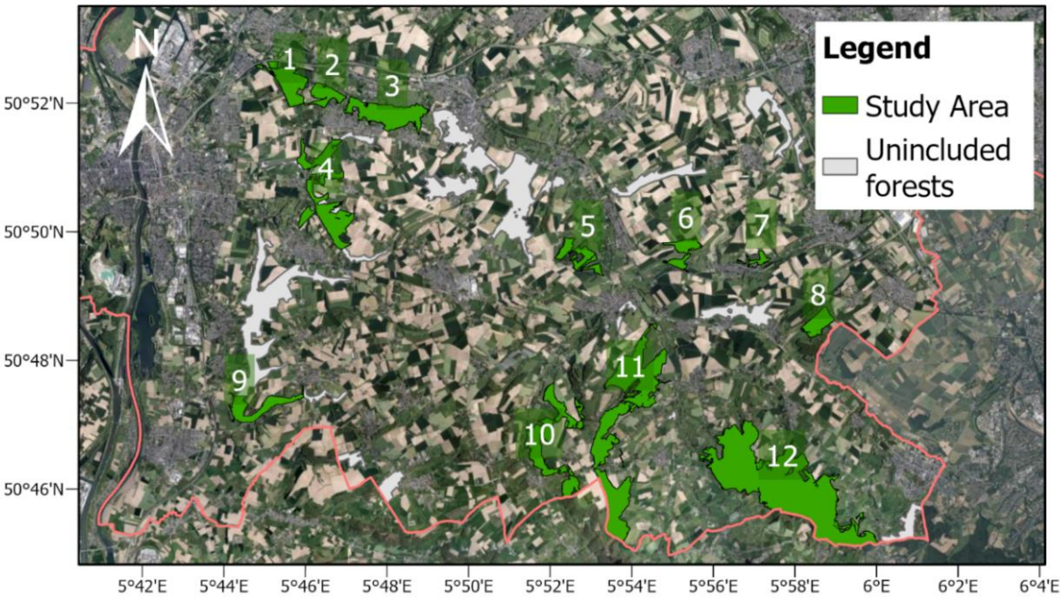
Pelage score	1 (Domestic)	2 (Intermediate)	3 (Wild)
1. Extent of dorsal stripe	Absent/covers entire tail	Continues onto tail	Stops at base of tail
2. Shape of tail tip	Tapered to a point	Intermediate	Blunt
3. Distinctness of tail bands	Absent/joined by dorsal line	Indistinct or fused	Distinct
4. Broken stripes on flanks	> 50% broken/no marking	25–50% broken	< 25% broken
5. Spots on flanks	Many/no marking	Some	None
6. Stripes on nape	Thin/ no stripes	Intermediate	4 thick stripes
7. Stripes on shoulders	Indistinct/no stripes	Intermediate	2 thick stripes

Figure 3: 7PS for a typical wildcat ***(A)*** *and domestic cat* ***(B).*** *Adapted from Kilshaw & Macdonald (2011)*

3.2 Camera trap study

Study area

For the camera trap study, I selected all forest areas south of the A79 highway and east of the A2 highway in the Netherlands which were either subject to a previous wildcat study, or part of the Natura 2000 network. There were eight forest areas for which I could not obtain a licence because of the risk to disturb vulnerable species. This left twelve forest areas for the study, as seen in figure 4. Six areas were last studied in 2019, two areas in 2017, and four areas have not been studied before: Curfsgroeve, Bemelerberg + Groeve 't Rooth, Landgoed Goedenraad and Savelsbos. The licence for Savelsbos was only viable for the southern arm of the forest. I selected the borders for each forest in ArcGIS Pro with the use of maps supplied by the forest management organisations Staatsbosbeheer (2021) and Limburgs Landschap (2021), or if these were not available, by selecting all consecutive forest land use types of the TOP10NL CAD vector dataset (Pdok, 2017).



#	Location	Area (ha)	Grid Cells	Most recent study
1	De Dellen	76	8	Kuipers (2019)
2	Curfsgroeve	39	4	None
3	Beneden Geuldal	119	12	Kuipers (2019)
4	Bemelerberg + Groeve 't	180	18	None
5	Dolsberg	50	5	Kuipers (2019)
6	Eyserbos	38	4	Kuipers (2017)
7	Landgoed Goedenraad	12	2	None
8	Platte Bosch	46	5	Kuipers (2019)
9	Savelsbos	65	7	None*
10	Groote Bosch	145	15	Kuipers (2019)
11	Bovenste Bosketen	364	37	Kuipers (2019)
12	Vijlenerbos	625	63	Kuipers (2017)
13	Total	1759	180	

*Figure 4: Camera trap study area and the number of grid cells each forest was divided into. *A small part in the most northern point of Savelsbos was studied by Kuipers (2019), but only two cameras were placed.*

For each forest, I aimed to place at least one camera per 10 ha. This spread ensured a low chance that there were wildcat territories where no cameras were placed. I divided the total area of each forest by 10 ha and rounded up to determine the preferred minimum number of cameras placed per forest. The forest polygons were then divided by the resulting number into grid cells with an equal area using the subdivide polygon data management tool from ARCGIS Pro. In the field, I tried to place one camera in each grid cell. Within each grid cell, I looked for locations that fit the following criteria: 1) not visible from pedestrian paths, to reduce risk of theft or destruction, 2) facing a wildlife track and 3) in an area with as much cover as possible from shrubs or dead wood. If there were multiple suitable locations, I selected the location that was nearest to the middle of the grid cell. For practical reasons, not all grid cells could be filled with cameras, and some grid cells had more than one camera. For example, some grid cells did not have any suitable locations based on the three criteria or turned out to be privately owned and were not accessible. If I had cameras left and no viable empty grid cells, I placed them in suitable locations in already filled grid cells, because I wanted to maximize the chance of recording sequences with wildcats.

Fieldwork

The fieldwork period lasted fifteen weeks from 29 November 2021 until 14 March 2022. The cameras stayed in one location between five and fifteen days before I relocated them to another location. In total, there were nine one-week periods, and three two-week periods of camera placement. I used 16 *Bushnell Natureview CamHD Essential 2015* cameras and 7 *Bushnell CORE™ DS-4K NO GLOW TRAIL CAMERA Model: 119987C* cameras. The cameras were installed to capture 30 second videos when triggered by infrared motion with a 10 second delay between consecutive videos. The video resolution was 1280 x 720 p. The sensor sensitivity was set to automatic, meaning that the cameras corrected for fluctuating temperatures during the fieldwork period. I attached the cameras to trees at a height of 0.5 m above the ground, with the centre of view aimed at a lure stick 2 metres in front of the camera. In this way, pelage markings on the back and the flanks of the cat were most visible.

I used a mixture of sunflower oil with valerian powder as lure. Valerian is widely used to attract wildcats (Janssen & Mulder, 2012; Kuipers, 2017). I used 250g valerian per litre of oil and let the mixture settle for at least one day. In the centre of view of each camera, I planted a stick vertically in the ground. I then poured roughly 20ml of the valerian oil over the stick. Due to a shortage of valerian powder in January, I used ground valerian root instead of powder in the last two months for the last three forests: Groote Bosch, Vijlenerbos and Bovenste Bosketen. Additionally, I sprinkled a handful of valerian flakes over the stick as well in the last three forests. I aimed to relocate each camera after one week, because the chance that unique individual animals are attracted to the lure on camera diminishes quickly after one week (Janssen & Mulder, 2013).

Analysis of recordings

I then watched the videos to register camera sequences of all medium-sized and large mammals that moved in front of the camera. A sequence of videos consisted of every recording within 5 minutes of the previous recording, unless it was clearly visible that there were different individuals. For every sequence, I noted the species and group size as well as the time of the start of the sequence. For sequences involving wildcats, hybrids or cases of doubt, I analysed the pelage markings to distinguish between different individual cats in one forest. For this purpose, I drew the pelage markings of each cat in an empty canvas adapted from the 7PS system from Kitchener et al. (2005) as seen in figure 3. I then scored each cat with 7PS to determine whether the cats had a phenotype of a wildcat or a domestic cat.

For every camera location, I determined characteristics of the surrounding environment. For an area of 20 by 20 metres around the camera, I counted the number of trees, and estimated the percentage of the basal cover by shrubs and deadwood respectively. I also classified the average shrub height in this area as 1 (<15cm), 2 (15-30cm) or 3(>30cm). These characteristics were then summarized in a table, along with the number of recordings for all animals other than cats. Even though I did not use data on other animals or environmental characteristics for this study, this database can be used for other studies.

Camera trap success

In total, the cameras captured 1624 trap nights on 190 different locations in 12 forests. One camera was stolen, and on three instances the camera malfunctioned and did have any recordings, which left 186 cameras with results. These cameras occupied 147 of 180 grid cells. 12 grid cells were not accessible. The remaining 21 grid cells did not have feasible locations, malfunctioning or stolen cameras, or I missed them by mistake. The coordinates, environmental characteristics and placement period for each camera is summarized in appendix B.

3.3 Spatial analysis

Habitat suitability model

For the habitat analysis, I used the wildcat habitat selection model by Klar et al. (2008). Their model is a use-versus-availability model that was built from a radio-telemetry database of positions of 6 female and 6 male wildcats between 2001 and 2004 in the Eifel. They randomly selected 121 positions per cat from the radio-telemetry database as a subsample of available site locations that the wildcat used. Then, they selected 121 random locations for each cat within their respective home range as a sample of availability. Based on previous literature, they fitted candidate generalized linear mixed models (GLMM) on the assumptions that wildcats prefer to be close to forests, meadows and riparian areas, and avoid human settlements, roads, and single buildings. The candidate model that best fitted the use and availability samples of their radio-telemetry database is formulated below.

$$\begin{array}{lll}
\text{logit(p)} = 1.14 & -0.013 \text{ x D\_Forest} & \\
 & -0.001 \text{ x D\_Meadow} & \\
 & -0.001 \text{ x D\_Water} & \\
\text{(IF D\_Village < 900)} & +0.002 \text{ x (D\_Village}-900) & \\
\text{(IF D\_House < 200)} & +0.004 \text{ x (D\_House}-200) & \\
\text{(IF D\_Road < 200)} & +0.002 \text{ x (D\_Road}-200) & (1)
\end{array}$$

$$p \;=\; \frac{e^{logit(p)}}{(1+e^{logit(p)}\,)} \qquad (2)$$

In the model, p is the relative probability that a cell of a matrix is used if it is available in a wildcat habitat as a function of distance (D) to the six environmental features mentioned above. Logit(p) is the logarithm of the odds $\frac{p}{(1-p\,)}$. We can see in formula 1 that the maximum value of logit(p) is 1.14, which corresponds to a maximum odds of ≈3.1 and a maximum probability of ≈0.76. This means that wildcats are ≈3.1 times more likely to use an optimal cell than to not use that cell. Higher distances to the preferred land types of forests, meadows and water decrease the value of logit(p). Proximity to villages, houses and roads also decrease logit(p) up until threshold distances of 900 meter for villages and 200 meters for houses and roads.

To evaluate their model, Klar et al. (2008) applied the model to matrixes of their training dataset in the Eifel, as well as to three evaluation datasets of different radio-telemetry datasets. Two of these datasets were in different areas in the Eifel, and one was in the Bienwald in Southern Germany. They found high and significant Spearman correlations in all four datasets with $r_s > 0.97$ and $P<0.001$ for all datasets in the Eifel, and $r_s = 0.91$ and $P<0.004$ for the dataset from Bienwald.

Methods

All analyses in this study were performed in ARCGIS Pro. I used the TOP10NL CAD 2017 v2 dataset (Pdok, 2017) for land use. This is a dataset from 2017 containing vectors for many different land use types. I reclassified the relevant features in the dataset to the six environmental features mentioned in formula (1) (See appendix A for the reclassifications). For roads, I used all roads with traffic speed limits of 50 km/h or higher. I did not include roads with lower speed limits because the amount of traffic and noise produced is lower on these roads, especially during the night, when wildcats are active. The dataset for villages did not include hamlets with less than 25 addresses. These were included in the single buildings feature layer. Then, I converted these factors into a raster dataset with a resolution of 25 * 25 m which rasterized features if the cell centre was in a feature. Because this resolution is larger than most roads and buildings, this caused the output raster dataset to have some holes in roads or buildings to be missed. However, upon visual inspection of the resulting rasters, most roads and hamlets remained their structural integrity, and distance to these features was not greatly affected as a result.

I then created a raster dataset with a resolution of 100*100m for the province of Limburg. I calculated the Euclidean distance from the centre of each grid cell to the closest cell centre of each environmental feature. If the centre of a grid cell was in an environmental feature, distances to that feature was set to 0. For cells with a distance greater than 900 meter to the nearest village, distance was reclassified to 900, and for cells with a distance greater than 200 meter to the nearest water cell or meadow cell, these respective distances were set to 200, so the last three components of formula (1) did not influence logit(p) beyond these thresholds. I then calculated p using formulas (1) and (2) in a raster dataset with a resolution of 100x100 meter.

A cell is a potential home range centre when there are [1] no villages within a circular area of 700 ha (radius of 1500 m) around the cell centre, [2] the 700 ha circular contains at least 185 ha of suitable habitat ($p > 0.45$), and [3] contains at least 94 ha of optimal habitat ($p > 0.65$) (Klar et al., 2008). I created 700 ha buffers around the centre of every cell in the raster dataset, and then selected the buffers which met these three conditions. I merged adjacent buffers to construct potential home ranges.

Because I did not calculate p for grid cells in Belgium, Germany, Gelderland and Brabant, grid cells within 1500 meter of the province border had smaller buffers, enclosed on one side by the border. To address this problem, I calculated the percentages of good and best habitat for all buffers which were partially outside of the border. I then selected all buffers which had >26% of good habitat and >13% of best habitat of the buffer area in Limburg. These percentages correspond to 185 ha of good habitat and 94 ha of best habitat in a regular 700 ha buffer. I included these buffers a separate category of suitable border regions. because it cannot be assumed that there is enough good and best habitat on the other side of the border to justify it as a potential home range.

Corridors

For the corridor analysis, I identified the most feasible routes between current and potential wildcat habitats within Limburg, as well as the major obstacles on these routes. I used a follow-up study from Klar et al. (2012) that built on the habitat selection model to identify the least-cost corridors in Limburg. In this study, they calculated cost surface as a function of p values with the following formula:

$$cost\ surface\ = (0.76 -\ p)\ {*}100 \qquad (3)$$

I applied this formula to create a raster dataset with cost surface values with a resolution of 100*100 meter. Since p has values between 0 for the worst habitats and 0.76 for optimal habitats, the resulting cost surface raster has values between 0 and 76. The underlying hypothesis behind this method is that wildcats are more likely to disperse through regions that are suitable as habitats, and less likely to disperse through regions that they would not use as habitats. Villages, highways and open water from the Top10NL dataset were given arbitrary scores of 1000 because they are major barriers for wildcat dispersal, and smaller roads with speed limits of 50 km/h or higher were given scores of 200 (Klar et al., 2012).

To identify the most cost-efficient corridor network in the camera trap study area, I used the optimal region connections function in ArcGIS PRO for the forests in Zuid-Limburg (see figure 1). This function searches the polyline that connects all forests while accumulating the lowest possible cost from the surface cost raster.

To study the most cost-efficient routes towards other potential home ranges in Limburg, I used the optimal path as line function. This function works slightly different than the region connection function in that it is directional from a starting point (source forest) to an ending point (destination forest). I used the Vijlenerbos and Bovenste Bosketen as source forests, as these are the only forests with a continued presence of more than one wildcat in the last ten years in the Netherlands, and they are the closest to the wildcat populations of the Eifel. I used the potential home ranges that resulted from the habitat analysis as destination forests. The result is a polyline that shows the corridor with the lowest cost from the source forests to all potential wildcat habitats. To identify major obstacles, I selected all villages, highways, and open water that the polylines cross. Crossings with smaller roads were classified as minor obstacles.

4. Results

4.1 Camera trap study

In total, I distinguished twelve different wild-living tabby cats in five forest areas (see figure 5). In Vijlenerbos, six wildcats and one domestic tabby cat appeared on camera. In Bovenste Bosketen, one wildcat and one domestic tabby cat visited camera locations in the northern parts of the forests. One wildcat each appeared in Savelsbos and a small forest patch south of Groote Bosch. In Eyserbos, one tabby cat was classified as indeterminate because the quality of the recording was too low to determine a 7PS score. I classified VBC7 and OBC2 as domestic cats because I gave them 7PS scores of 14 and 13 respectively, and they had at least one typical domestic cat characteristic. VBC7 did not have distinct tail bands, and OBC2 had many broken stripes and spots on their flanks. I discussed these cats with René Janssen of Bionet and Hettie Meertens of ARK Nature. We concluded that these cats might be hybrids or backcrosses, but there is no way to tell for certain by pelage marking analysis. I decided to keep their indication of domestic cats to make conservative estimates of wildcat presence. Camera traps in the other forests from this study did not have any recordings of wildcats. In table 1, the number of individuals in each forest is summarized, including non-tabby domestic cats.

Location	**Cameras**	**Trap nights**	**Wildcats**	**Domestic tabby cats**	**Other domestic cats**	**Lure (valerian)**
De Dellen	6	42	0	0	0	Powder
Curfsgroeve	7	49	0	0	0	Powder
Beneden Geuldal	14	97	0	0	4	Powder
Bemelerberg + GR	13	89	0	0	5	Powder
Dolsberg	5	25	0	0	0	None
Eyserbos	4	36	0-1	0-1	0	Powder
Landgoed Goedenraad	2	14	0	0	0	Powder
Platte Bosch	5	35	0	0	0	Powder
Savelsbos	8	105	1	0	0	Powder
Groote Bosch	24	160	1	1	0	Flakes
Bovenste Bosketen	38	257	1	1	1	Flakes
Vijlenerbos	59	650	6	1	1	Flakes
Total	190	1624	9-10	3-4	11	-

Table 1: Number of individual cats that appeared on camera in each forest.

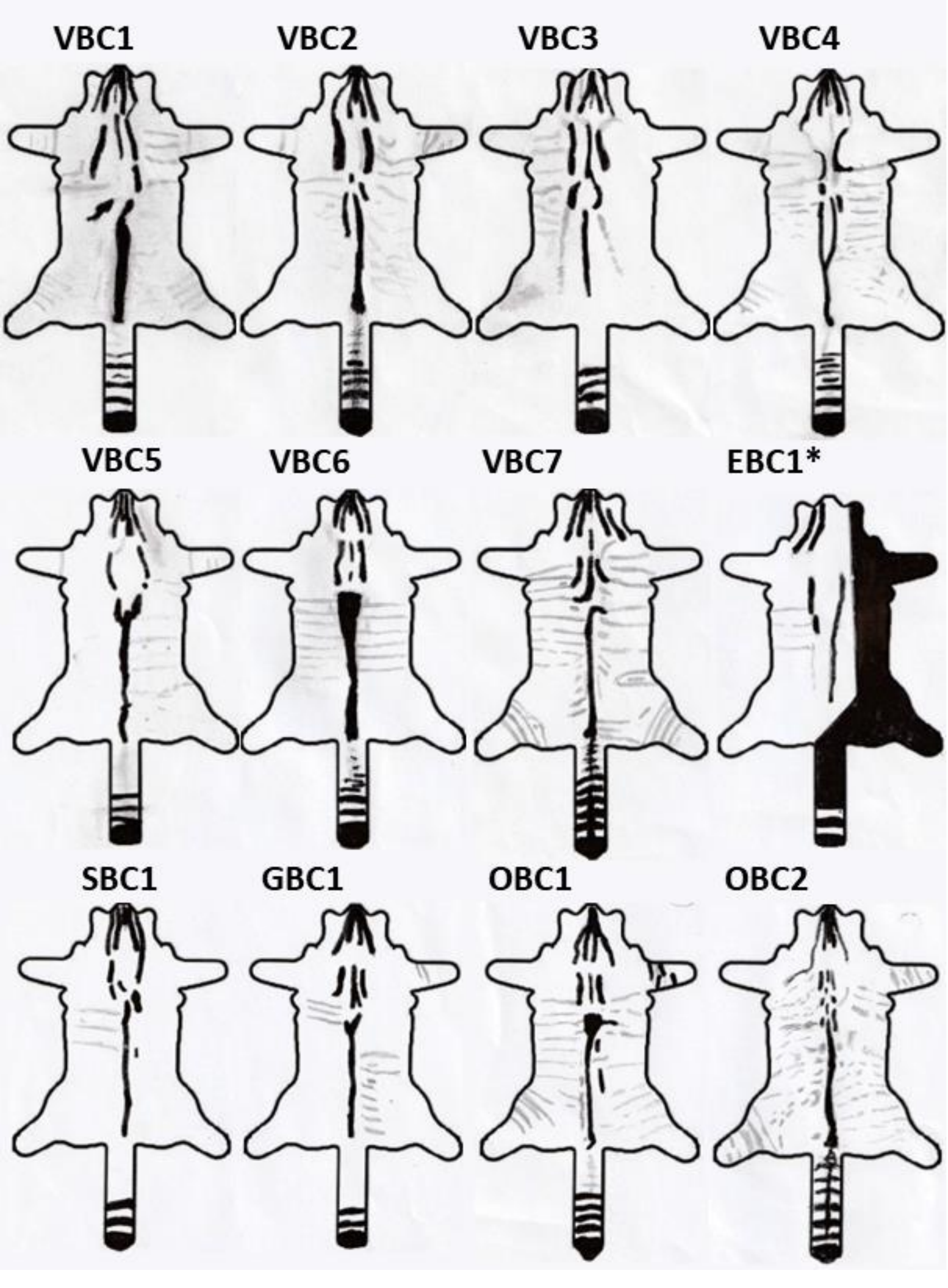


*Figure 6: Pelage marking sketches of all tabby cats in this study. *The solid black part on the right flank of EBC1 could not be seen on camera.*

Cat	1. Extent of dorsal stripe	2. Shape of tail tip	3. Distinctness of tail bands	4. Broken stripes on flanks	5. Spots on flanks	6. Stripes on nape	7. Stripes on shoulders	Total	Verdict
SBC1	3	2	3	3	3	3	2	19	WC
EBC1	?	3	?	2	?	?	?	?	INDET
GBC1	3	3	3	2	3	3	3	20	WC
OBC1	3	2	3	3	3	3	3	19	WC
OBC2	3	2	2	1	1	2	2	13	DC
VBC1	3	3	3	2	2	3	3	19	WC
VBC2	2	2	2	2	2	3	3	16	WC
VBC3	3	3	3	2	3	3	3	20	WC
VBC4	2	2	2	2	2	3	3	16	WC
VBC5	3	3	3	3	2	3	2	19	WC
VBC6	3	2	3	3	3	3	3	20	WC
VBC7	2	2	1	2	2	3	2	14	DC

Table 2: 7PS for all observed tabby wild-living cats in our study. WC = Wild cat. DC = Domestic cat. INDET = Indeterminate

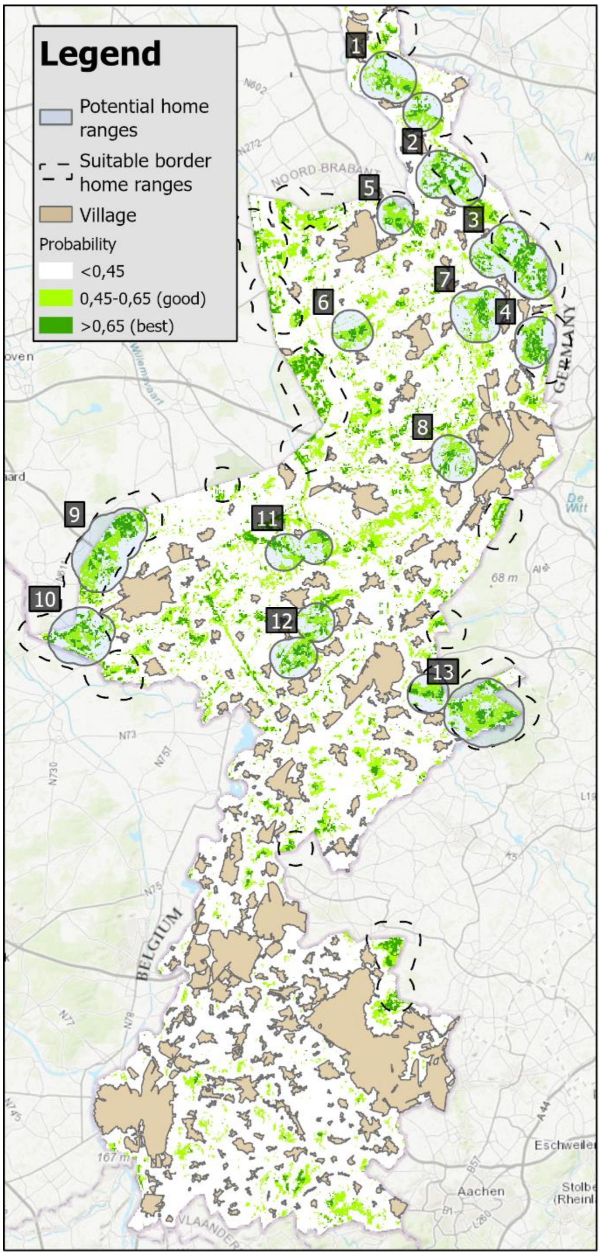
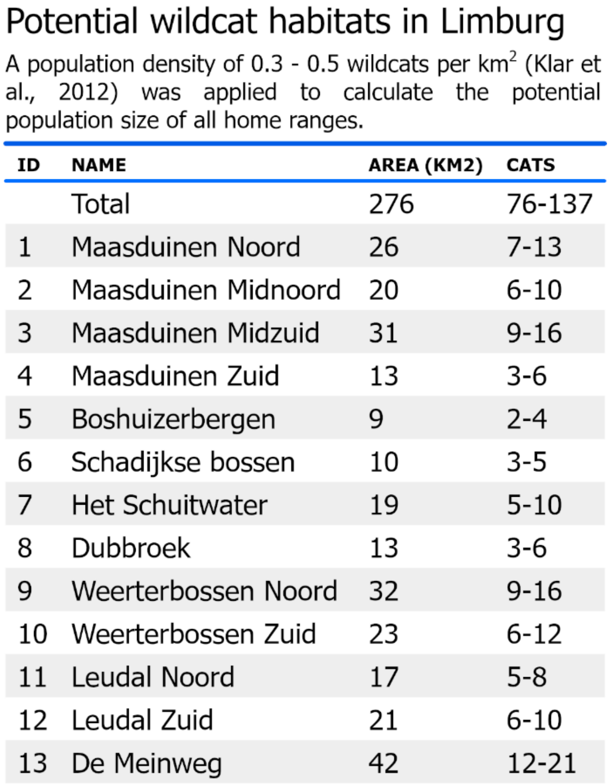


Figure 7: Potential wildcat home ranges in Limburg.

4.2 Habitat suitability

The suitability model calculated 87 km^2 of optimal habitat (3.9%) and 230 km^2 of good habitat (10.3%) within the 2213 km^2 area of the province of Limburg. Most suitable habitat is situated in Noord-Limburg, as seen in figure 7.

There are 13 forest areas in Limburg that satisfy the three conditions for a suitable wildcat home range with a cumulative area of 276 km^2. All of them are situated in Noord- or Midden-Limburg.



Potential wildcat habitats in Limburg

A population density of 0.3 - 0.5 wildcats per km^2 (Klar et al., 2012) was applied to calculate the potential population size of all home ranges.

ID	NAME	AREA (KM2)	CATS
	Total	276	76-137
1	Maasduinen Noord	26	7-13
2	Maasduinen Midnoord	20	6-10
3	Maasduinen Midzuid	31	9-16
4	Maasduinen Zuid	13	3-6
5	Boshuizerbergen	9	2-4
6	Schadijkse bossen	10	3-5
7	Het Schuitwater	19	5-10
8	Dubbroek	13	3-6
9	Weerterbossen Noord	32	9-16
10	Weerterbossen Zuid	23	6-12
11	Leudal Noord	17	5-8
12	Leudal Zuid	21	6-10
13	De Meinweg	42	12-21

The model identifies no suitable home ranges in Zuid-Limburg because of high densities of villages, roads, and buildings in this region. If we assume a wildcat density of 0.3 – 0.5 km^2, the home ranges as seen in figure 7 have potential cumulative subpopulations of 76 – 137 wildcats. If we count suitable border home regions as well, then there are 8 more suitable home ranges with a total area of 170 km^2 in Limburg. The three forest areas with the largest suitable home ranges are the Maasduinen (ID 1 t/m 4) with a combined area of 90 km^2 of suitable home range and 25-42 potential cats, Weerterbossen (ID 9 & 10) with a combined area of 55 km^2 and 9-28 cats, and the Meinweg (ID 13) with an area of 42 km^2 and 12-21 cats.

4.3 Corridors

Movement cost between source forests and suitable home ranges is generally highest in Zuid-Limburg and Midden-Limburg (see figure 8). Furthermore, there are 61 major obstacles on the corridors within Limburg between the source forest patches and the destination suitable home ranges. The towns of Sittard and Geleen on the border of Midden- and Zuid-Limburg form notable barriers for wildcat dispersal. Even the lowest cost paths have 10 major obstacles in Sittard and Geleen alone.

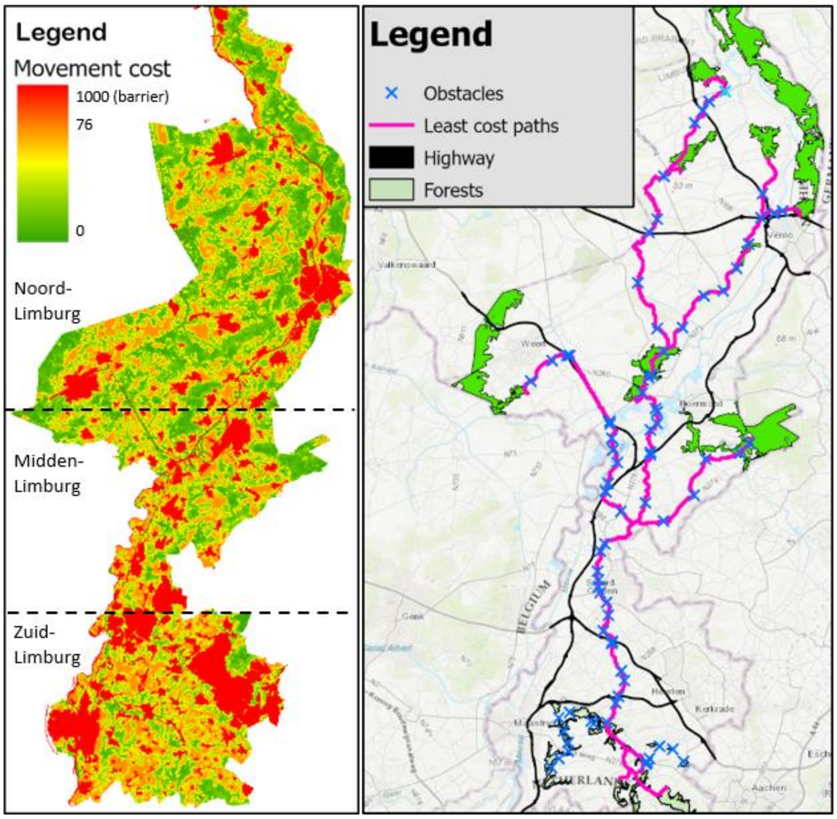


Figure 8: Movement cost (left), and least cost paths between source forests and suitable home ranges on them (right)

If we look at the best current corridor network in our camera trap study area, the most cost-efficient network is a 50 km polyline that moves north from Vijlenerbos and Bovenste Bosketen, diverges to Platte Bosch in the east, and loosely follows the Geul to the west, from where it eventually moves south again to Savelsbos. In this corridor network, there are six major obstacles for wildcat dispersal. These are three crossings with the river Geul, two crossings with provincial road N278, one crossing through the villages of Partij and Wittem. Furthermore, there are fourteen crossings with smaller roads which act as minor obstacles.

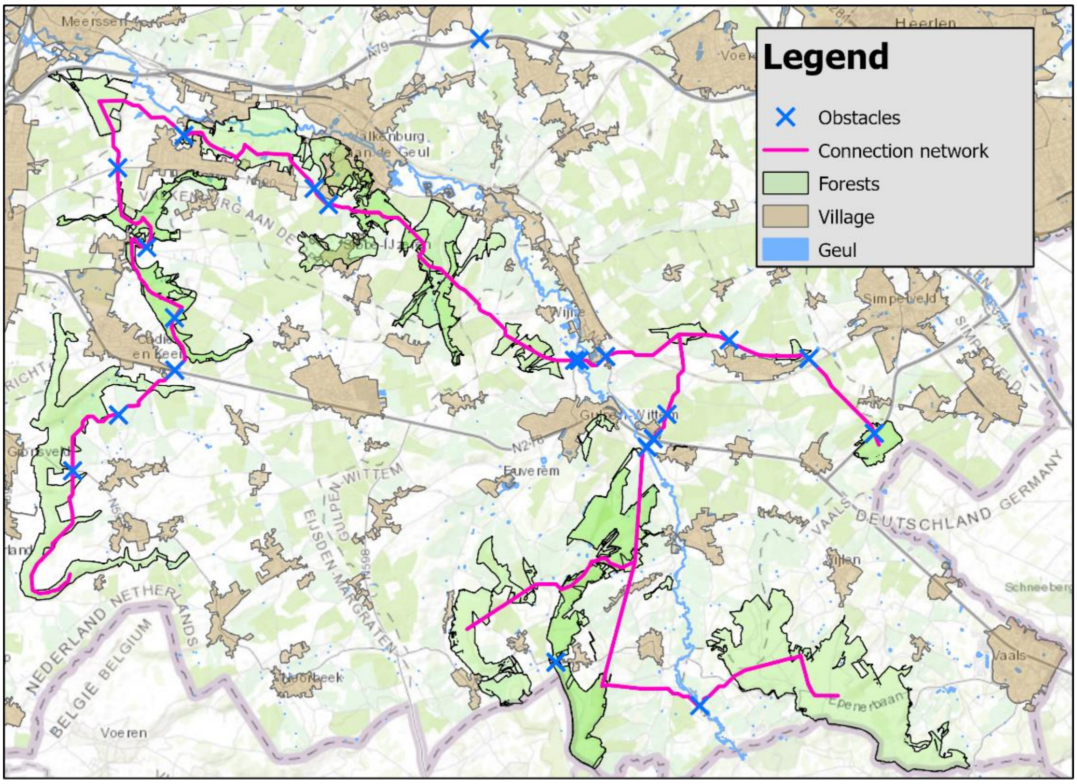


Figure 9: Current optimal corridor network and major and minor obstacles in Zuid-Limburg

5. Conclusion

With this study, I aimed to contribute to the knowledge on wildcat habitat and corridor suitability in the Netherlands. The first research question was what the current state of the population of the European wildcat is in Zuid-Limburg. I identified nine distinct wildcats in the study area. Six of these were in Vijlenerbos, and one each in Groote Bosch, Bovenste Bosketen and Savelsbos. Furthermore, one indeterminate cat and two cats with a mix of wildcat and domestic cat phenotypical characteristics appeared on cameras in Eyserbos, Bovenste Bosketen and Vijlenerbos. Thus, nine individuals in the twelve forest areas in this study is a conservative estimate of wildcat presence.

The second research question was what the most suitable potential wildcat habitats are in Limburg. These are the Maasduinen (90 km^2 of suitable habitat), Weerterbossen (55 km^2), and de Meinweg (42 km^2). Other smaller suitable home ranges are Leudal Zuid (21 km^2), Leudal Noord (17 km^2) Het Schuitwater (19 km^2), Dubbroek (13 km^2), Schadijkse Bossen (10 km^2), Boshuizerbergen (9 km^2). In total, these areas can hold cumulative subpopulations of 76-137 wildcats. Even though wildcats are present in Zuid-Limburg, the spatial analysis indicated that habitat patches are too small, too close to villages, or do not have enough good habitat and best habitat available e.g., habitat quality is low.

The third and final research question was what the routes are that wildcats can use to transition between current and potential habitats. Currently, wildcats exclusively present in Zuid-Limburg. The lowest cost connection network that connects the forests of the camera trap study is 50 km. This network loosely follows the river Geul and branches out to Savelsbos and Platte Bosch. On this corridor network, there are six major obstacles with villages, the N278 and the river Geul, and fourteen minor obstacles. For wildcats to reach all suitable home ranges in Midden- and Noord-Limburg taking a route only through Limburg, they need to cross 61 major obstacles. Movement cost and the number of obstacles is especially high in Midden-Limburg, where there are many villages and highways, and little forest areas.

6. Discussion

Field work limitations

The main limitation of the fieldwork was the change in lure from ground valerian root to valerian flakes for the last three forests (Groote Bosch, Vijlenerbos and Bovenste Bosketen). Cats in these forests interacted longer with the lure stick than the cats in Savelsbos and Eyserbos. This suggests that the first lure method had a lower chance of attracting wildcats. Furthermore, some forests had slightly higher camera densities than others (see figure 5). When interpreting the results of this study, it is important to acknowledge that I was more likely to detect presence of wildcats in some forests than others because of differences in lure method and camera densities. Camera traps are never guaranteed to detect presence of wildcats in an area. Therefore, the number of wildcats observed in this study should be seen as the minimum of wildcats present in that area, and it cannot be excluded that there are wildcats present in areas where they were not observed in this study.

Spatial analysis limitations

The model by Klar et al. (2008) has the advantage that it is simple to implement for large areas because it only requires the distance to six environmental features to function. This simplicity also causes some problems for model accuracy, because the model does not account for the size and quality of features. In the model, small patches influence p in the same way that larger patches would, while this seems unlikely in reality. This is partially accounted for by the selection criteria of suitable home ranges, because these home ranges require a minimum area 26% of good habitat. It is likely that these good habitat patches are connected. Upon visual inspection of the resulting home ranges from this study, all suitable home ranges have connected patches of good habitat (p >0.45) except for Leudal Noord and Maasduinen Midzuid, where the home ranges include 2 patches of connected good habitat, separated by unsuitable habitat (p<0.45). However, movement cost between these patches was low (see figure 9), so these areas might still be suitable as wildcat habitats.

Patch quality is not included in the model because Klar et al. (2008) stated that forest and meadow types did not have any effect on habitat use in preliminary analyses in the Eifel. On the other hand, the telemetry study in Vijlenerbos by Janssen et al. (2015) suggests that wildcats have preferences for certain forest and meadow types with more cover. The dataset from the Top10NL dataset which I used (Pdok, 2017) had many meadow features which resulted in low meadow distance values for every grid cell. The dataset also included farmland, which offers less cover and prey then natural grasslands (Janssen et al., 2016). Model accuracy can be improved by modifying the model to include meadow and forest quality. Lastly, I did not use data from features outside of Limburg. This means that some p values of grid cells near the border are inaccurate, because the closest distance to an environmental feature is not always within Limburg.

Relation to previous literature

Wildcat presence in this study is slightly different from the studies from Kuipers (2019, 2017), which used similar methods. The subpopulation in Vijlenerbos has likely remained at a similar size, as I found 6 adult wildcats, compared to the 8 adults in 2017. VBC1 appears to be the same cat as WKVB1 from Kuipers (2017), and VBC5 from this study is the same cat as WKVB2 from Kuipers (2017). Other wildcats in this study did not show convincing similarities to cats from Kuipers (2016, 2017, 2019), Janssen et al. (2006) or Janssen & Mulder (2013). In Bovenste Bosketen, I observed one wildcat and one domestic tabby cat in Bovenste Bosketen, and one wildcat in Roebelsbosch south of Groote Bosch. Studies from Kuipers (2017, 2019) found 2 and 3 different cats in these forests. Neither of these cats showed again in 2022, which suggests that dispersal through these forests is high.

Wildcat population dynamics in Limburg

One of the criteria for a metapopulation among medium-sized mammals is that there are discrete breeding subpopulations (Elmhagen & Angerbjörn, 2001). I observed the highest presence of wildcats in Zuid-Limburg in Vijlenerbos with six individuals. However, home ranges of wildcats in Vijlenerbos can extend into Aachener Wald (Janssen et al., 2016) which was not a part of this study. Thus, the subpopulation of wildcats in Vijlenerbos and Aachener Wald might be larger than six wildcats. Despite this, it remains unlikely that the subpopulation is large enough to hold a discrete breeding subpopulation. Klar et al. (2012) use 50 individuals as a minimum for a breeding wildcat subpopulation. The habitat suitability analysis also revealed that the forest patches in Zuid-Limburg are too small to be suitable home ranges.

If the wildcats from this study use the forest patches in which they were observed as their home range, risks of local (pseudo-)extinctions in patches are high. This might explain why I did not observe wildcats in Platte Bosch, even though it is an isolated patch where a wildcat was observed in 2019. If we view the wildcats of Zuid-Limburg as part of the Central-European metapopulation (Mattucci et al., 2016), mainland-island population dynamics seem to be the most relevant. The wildcat population in the Eifel acts as a mainland population with a large population size (Birlenbach et al., 2009; Franck, 2010), while the smaller fragmented forest patches of Zuid-Limburg can be seen as island populations with negative growth rates and high risks of (pseudo-)extinctions (Hoopes & Harrison, 1998), meaning they are still reliant on dispersal from the Eifel.

Implications for conservation

To improve habitat- and corridor quality in Zuid-Limburg, it is necessary to connect the current forest patches with a network of green corridors. In this way, the smaller forest patches can act as one large patch (Klar et al., 2012), in which risks of extinction and hybridization are lower. The connection network I created with the least-cost path (see figure 9) can serve as an indication where green corridors can be established, as these are the paths with the lowest cost that wildcats can take to other habitat patches. Crossings with roads and the river Geul are the most important obstacles to overcome. These obstacles pose additional challenges when designing corridor networks. Possible ways to mitigate the risk of road mortality are wildcat fences in combination with road underpasses (Klar et al., 2009).

Even though the presence of wildcats in Zuid-Limburg has increased in the last years, areas in Noord-Limburg might offer even more suitable home ranges. However, the routes from Zuid-Limburg to these areas have high costs within Limburg. It might be more feasible to establish corridors through Belgium and Germany. Conservationists in the Netherlands, Belgium and Germany should cooperate and share data to construct corridor networks that increase ecological connectivity and allow for the dispersal of wildcats and other animals.

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8. Appendices

Appendix A: GIS conversion table

TOP10NL	Model	TOP10NL	Model
13000	Building	10410	Road
13100	Building	10413	Road
13300	Building	10513	Road
13400	Building	10713	Road
14060	Forest	18400	Village
14070	Forest	12400	Water
14080	Forest	12410	Water
14082	Forest	12415	Water
14090	Forest	12420	Water
14130	Grassland	12430	Water
14132	Grassland	12435	Water
14140	Grassland	12500	Water
10200	Road	12505	Water
10201	Road	12600	Water
10310	Road	12800	Water
10400	Road	12810	Water

Appendix B: Camera sites

Appendix C: Sequences with cats

Camera	Dutch name	*Species*	Cat	Date and time
GD2	Huiskat	*Felis silvestris catus*	GD DC1	9-12-21 21:14
GD2	Huiskat	*Felis silvestris catus*	GD DC2	13-12-21 6:46
GD4	Huiskat	*Felis silvestris catus*	GD DC3	12-12-21 6:44
GD4	Huiskat	*Felis silvestris catus*	GD DC3	13-12-21 4:46
GD6	Huiskat	*Felis silvestris catus*	GD DC4	8-12-21 19:58
BB13	Huiskat	*Felis silvestris catus*	BB DC1	16-12-21 20:14
BB13	Huiskat	*Felis silvestris catus*	BB DC1	17-12-21 20:47
BB13	Huiskat	*Felis silvestris catus*	BB DC2	18-12-21 1:56
BB13	Huiskat	*Felis silvestris catus*	BB DC1	19-12-21 21:55
BB13	Huiskat	*Felis silvestris catus*	BB DC1	19-12-21 23:07
GR10	Huiskat	*Felis silvestris catus*	GR DC1	20-12-21 9:38
SB2	Wilde kat	*Felis silvestris silvestris*	SB WC1	23-12-21 21:32
SB4	Wilde kat	*Felis silvestris silvestris*	SB WC1	26-12-21 1:23
SB4	Wilde kat	*Felis silvestris silvestris*	SB WC1	1-01-22 21:17
SB4	Wilde kat	*Felis silvestris silvestris*	SB WC1	1-01-22 21:59
SB6	Wilde kat	*Felis silvestris silvestris*	SB WC1	28-12-21 6:57
SB12	Wilde kat	*Felis silvestris silvestris*	SB WC1	1-01-22 18:04
BU8	Huiskat	*Felis silvestris catus*	BU DC1	27-12-21 6:02
BU8	Huiskat	*Felis silvestris catus*	BU DC2	31-12-21 1:07
KB10	Huiskat	*Felis silvestris catus*	KB DC1	1-01-22 3:52
KB10	Huiskat	*Felis silvestris catus*	KB DC1	29-12-21 17:37
EB8	Wilde kat	*Felis silvestris silvestris*	EB WC1	7-01-22 21:22
GB3	Huiskat	*Felis silvestris catus*	GB DC1	23-01-22 8:57
GB5	Huiskat	*Felis silvestris catus*	GB DC1	19-01-22 9:35
GB5	Huiskat	*Felis silvestris catus*	GB DC1	19-01-22 9:52
GB22	Wilde kat	*Felis silvestris silvestris*	GB WC1	20-01-22 20:57
VB1	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-22 4:22
VB1	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-22 4:44
VB1	Wilde kat	*Felis silvestris silvestris*	VB WC1	7-02-22 21:36
VB2	Wilde kat	*Felis silvestris silvestris*	VB WC1	26-01-22 5:43
VB2	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-21 19:52
VB2	Wilde kat	*Felis silvestris silvestris*	VB WC1	29-01-21 1:30
VB2	Wilde kat	*Felis silvestris silvestris*	VB WC1	2-02-21 1:50
VB2	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	3-02-21 18:15
VB2	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	4-02-21 23:35
VB3	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-22 4:05
VB3	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-22 4:20
VB3	Wilde kat	*Felis silvestris silvestris*	VB WC1	7-02-22 21:36
VB4	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	27-01-21 6:51
VB4	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	27-01-21 22:16
VB4	Wilde kat	*Felis silvestris silvestris*	VB WC1	7-02-21 19:35

VB5	Wilde kat	*Felis silvestris silvestris*	VB WC1	29-01-22 22:15
VB6	Wilde kat	*Felis silvestris silvestris*	VB WC1	25-01-22 22:29
VB6	Wilde kat	*Felis silvestris silvestris*	VB WC1	2-02-22 4:46
VB9	Wilde kat	*Felis silvestris silvestris*	VB WC1	24-01-22 19:46
VB9	Wilde kat	*Felis silvestris silvestris*	VB WC1	25-01-22 23:21
VB9	Wilde kat	*Felis silvestris silvestris*	VB WC1	28-01-22 22:38
VB12	Wilde kat	*Felis silvestris silvestris*	VB WC1	25-01-22 3:58
VB12	Wilde kat	*Felis silvestris silvestris*	VB WC1	25-01-22 4:24
VB12	Wilde kat	*Felis silvestris silvestris*	VB WC1	25-01-22 4:42
VB14	Wilde kat	*Felis silvestris silvestris*	VB WC1	3-02-22 18:51
VB14	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	28-01-22 6:22
VB14	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	30-01-22 7:59
VB14	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	3-02-22 7:01
VB16	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	27-01-22 6:54
VB17	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	14-02-22 19:16
VB17	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	21-02-22 3:52
VB19	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	22-02-22 7:23
VB19	Wilde kat	*Felis silvestris silvestris*	VB WC1	21-02-22 23:54
VB20	Wilde kat	*Felis silvestris silvestris*	VB WC1	9-02-22 5:11
VB25	Wilde kat	*Felis silvestris silvestris*	VB WC2	10-02-22 5:54
VB28	Huiskat	*Felis silvestris catus*	VB DC2	20-02-21 1:31
VB29	Huiskat	*Felis silvestris catus*	VB DC2	20-02-22 1:56
VB29	Huiskat	*Felis silvestris catus*	VB DC2	20-02-22 19:44
VB29	Twijfelkat	*Felis silvestris catus*	VB DoubtC1	21-02-22 5:02
VB31	Wilde kat	*Felis silvestris silvestris*	VB WC3	17-02-22 19:49
VB31	Twijfelkat	*Felis silvestris catus*	VB DoubtC1	18-02-22 20:43
VB32	Wilde kat	*Felis silvestris silvestris*	VB WC4	11-02-22 19:35
VB32	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	12-02-22 21:30
VB32	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	13-02-22 3:39
VB32	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	16-02-22 6:06
VB32	Twijfelkat	*Felis silvestris (silvestris/catus)*	VB DoubtC1	18-02-22 20:54
VB32	Wilde kat	*Felis silvestris silvestris*	VB WC3	19-02-22 3:30
VB32	Wilde kat	*Felis silvestris silvestris*	VB WC5	19-02-22 19:54
VB35	Wilde kat	*Felis silvestris silvestris*	VB WC3	9-02-22 2:05
VB39	Wilde kat	*Felis silvestris silvestris*	VB WC6	21-02-22 22:36
VB39	Wilde kat	*Felis silvestris silvestris*	VB WC6	21-02-22 23:14
VB46	Wilde kat	*Felis silvestris silvestris*	VB WC6	25-02-22 23:28
VB48	Wilde kat	*Felis silvestris silvestris*	VB WC5	24-02-22 9:16
VB48	Wilde kat	*Felis silvestris silvestris*	VB WC5	25-02-22 1:31
VB49	Wilde kat	*Felis silvestris silvestris*	VB WC6	25-02-22 20:15
VB52	Wilde kat	*Felis silvestris silvestris*	VB WC5	24-02-22 22:31
VB52	Wilde kat	*Felis silvestris silvestris*	VB WC5	25-02-22 15:42
VB52	Wilde kat	*Felis silvestris silvestris*	VB WC5	25-02-22 19:15
VB52	Wilde kat	*Felis silvestris silvestris*	VB WC5	25-02-22 23:45
VB52	Wilde kat	*Felis silvestris silvestris*	VB WC5	26-02-22 13:08
VB54	Wilde kat	*Felis silvestris silvestris*	VB WC6	24-02-22 20:30
VB54	Wilde kat	*Felis silvestris silvestris*	VB WC5	27-02-22 4:34
VB55	Wilde kat	*Felis silvestris silvestris*	VB WC6	23-02-22 21:19

VB55	Wilde kat	*Felis silvestris silvestris*	VB WC6	23-02-22 22:42
VB57	Wilde kat	*Felis silvestris silvestris*	VB WC5	23-02-22 2:27
VB57	Wilde kat	*Felis silvestris silvestris*	VB WC5	24-02-22 2:55
VB57	Wilde kat	*Felis silvestris silvestris*	VB WC5	25-02-22 21:05
OB13	Huiskat	*Felis silvestris catus*	OB DC1	6-03-22 20:41
OB14	Wilde kat	*Felis silvestris silvestris*	OB WC1	1-03-22 23:16
OB19	Wilde kat	*Felis silvestris silvestris*	OB WC1	3-03-22 19:16
OB23	Twijfelkat	*Felis silvestris (silvestris/catus)*	OB DoubtC1	26-02-22 4:03
OB25	Twijfelkat	*Felis silvestris (silvestris/catus)*	OB DoubtC1	9-03-22 3:03
OB29	Wilde kat	*Felis silvestris silvestris*	OB WC1	7-03-22 20:33
OB29	Wilde kat	*Felis silvestris silvestris*	OB WC1	9-03-22 23:04
OB30	Wilde kat	*Felis silvestris silvestris*	OB WC1	9-03-22 23:19
OB30	Wilde kat	*Felis silvestris silvestris*	OB WC1	14-03-22 4:42
OB32	Twijfelkat	*Felis silvestris (silvestris/catus)*	OB DoubtC1	11-03-22 23:13
OB36	Twijfelkat	*Felis silvestris (silvestris/catus)*	OB DoubtC1	9-03-22 19:07
OB36	Wilde kat	*Felis silvestris silvestris*	OB WC1	11-03-22 2:18

Appendix D: Wildcats

Figure E1: EBC1

Figure E2: SBC1

Figure E3: GBC1

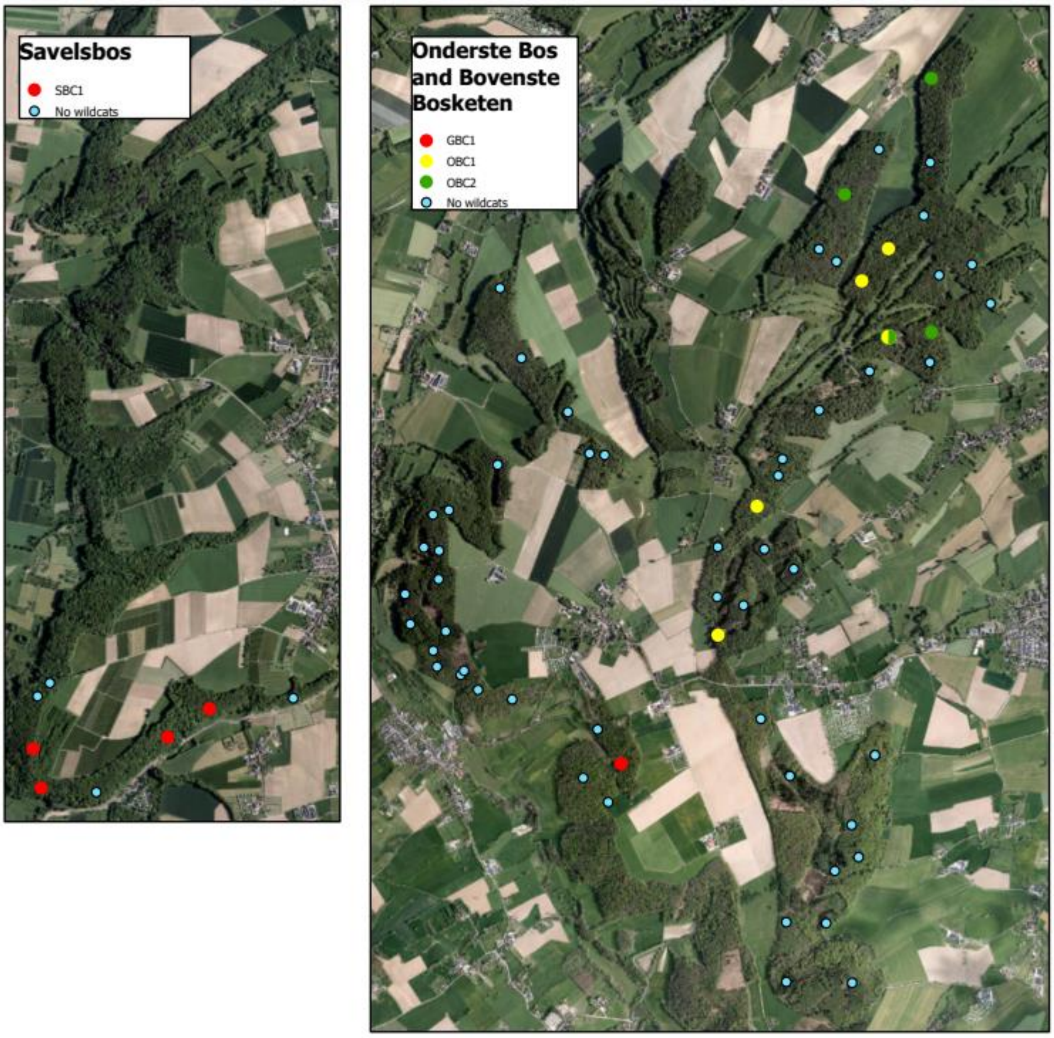

Figure E4: Cat sightings in Savelsbos, Groote Bosch and Bovenste Bosketen

Figure E5: OBC1

Figure E6: OBC2

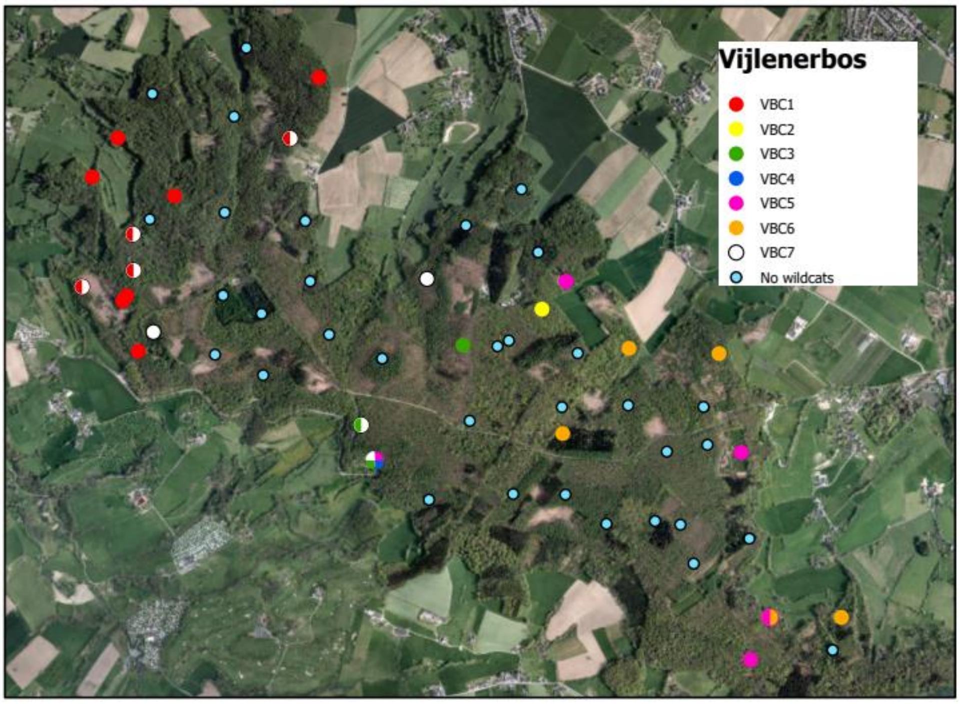

Figure E7: Cat sightings in Vijlenerbos

Figure E8: VBC1

Figure E9: VBC2

Figure E10: VBC3

Figure E11: VBC4

Figure E12: VBC5

Figure E13: VBC6

Figure E14: VBC7

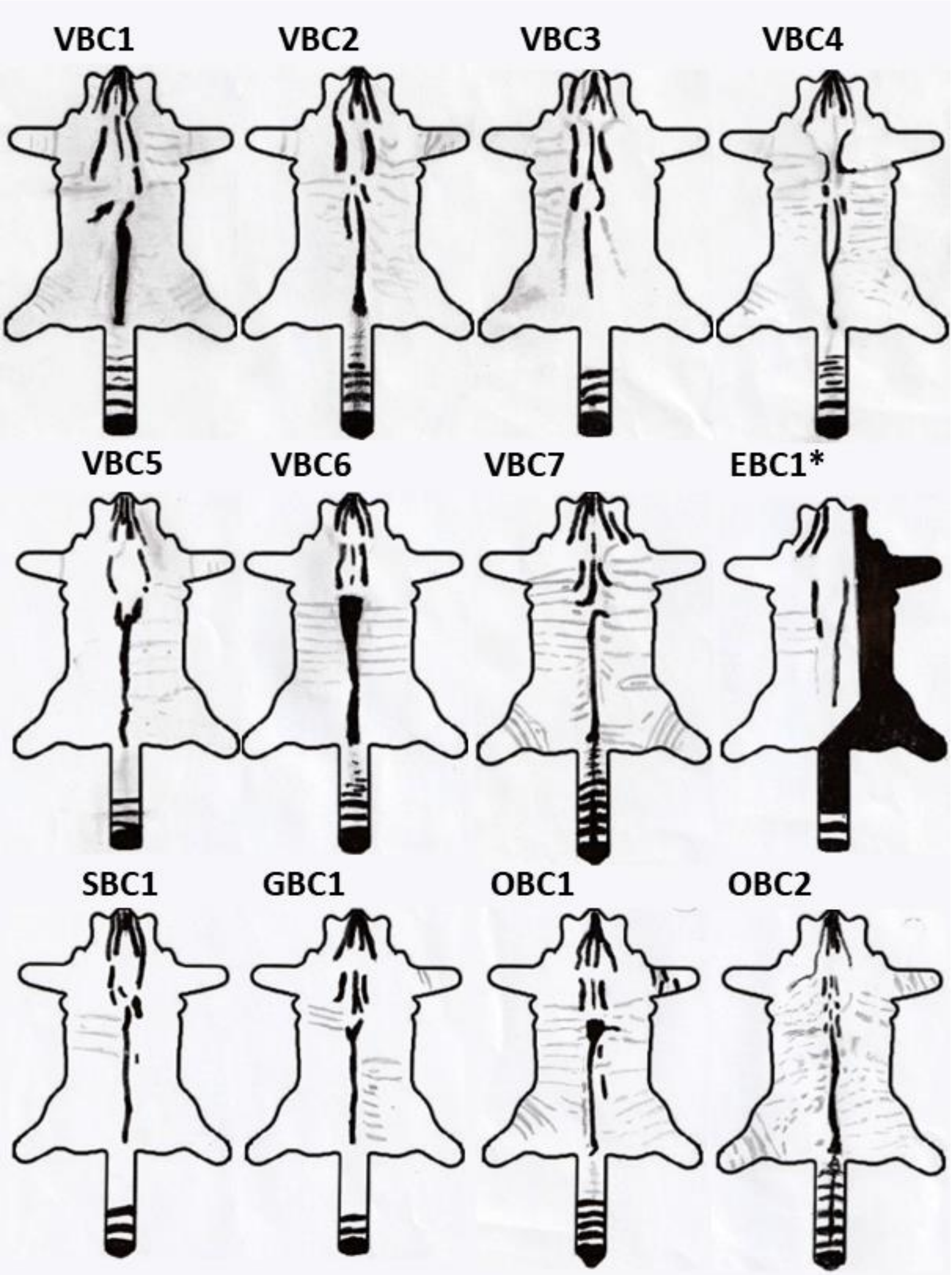

Figure E15

Appendix E: Environmental features used in the model