Crossing possibilities for wildcats at a highway in Belgium

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Content

1. Summary (English)

Recently, several animal species are making their comeback in the Netherlands. One of these species is the European wildcat (*Felis silvestris silvestris*). Wildcats are increasing in the German Eifel and Belgium Ardennes, resulting in a movement to other areas such as South-Limburg. Although there are some recent observations of wildcats in the Netherlands, for a real comeback there are still some threats, such as hybridisation risk with domestic cats and being killed by traffic or by hunters. One of the major roads wildcats are very likely to cross in order to reach the Netherlands is the E40 in Belgium (Liège-Aachen). This highway has only one ecoduct for wildlife crossing, near Welkenraedt. Other crossing structures including overpasses, underpasses and culverts are built for humans, but might be used by animals such as wildcats as well.

This research has investigated crossing structures of the highway E40 in Belgium (Liège-Aachen). First of all, the locations of the crossing structures and their characteristics like berm, vegetation, lighting, human disturbance, pavement and road markings have been determined and measurements and photos have been taken. Secondly, at some of the crossing structures cameras have been placed, to determine if wildcats or other animals are using it. At the 17 km long highway section 56 crossing structures are located, consisting of 12 overpasses, 10 underpasses and 34 culverts. At 12 crossing structures cameras with lure sticks have been placed to attract wildcats. No wildcats are recorded, in contrast to domestic cats which occur at almost all crossing structures. Furthermore, other animal species such as dog, horse, badger, bird, deer, fox, lagomorph, mice, small mustelid and squirrel are recorded. Several animals seem interested in the lure sticks. The ecoduct functions well, as it is frequently used by wild animals. It seems that the level of humans passing's on crossing structure negatively affects that of wild animals.

Overpasses seem to be least suitable for wildcats and other animal species for crossing the highway, mainly due to high traffic. Short underpasses which are generally used by pedestrians seem to be more suitable for animals such as badgers. In addition, culverts are also suitable for wildlife crossing for animals such as foxes, which have used culverts regularly. These crossing structures are often situated at locations which are not directly accessible to humans. Some adjustments to the many available crossing structures, like more vegetation and shelter, could improve the use of wildcats and other animal species. Additionally, shelves can be placed in (large) culverts which contain water. Placing fences at the highway can decrease direct crossing of the highway and rasters can be placed to guide animals to the crossing structures. This all would give the wildcat a better chance to cross the highway E40 in Belgium and to make a successful comeback to the Netherlands.

2. Summary (Dutch)

Net zoals veel andere diersoorten, is de Europese wilde kat (*Felis silvestris silvestris*) bezig met zijn terugkeer naar Nederland. Het aantal wilde katten in de Duitse Eifel en Belgische Ardennen neemt de laatste jaren toe, waardoor de territoria vol raken en wilde katten naar andere gebieden zoals Zuid-Limburg trekken. De afgelopen jaren worden dan ook steeds vaker wilde katten in Zuid-Limburg gespot. Voordat de wilde kat een succesvolle terugkeer kan maken in Nederland is er een aantal obstakels te overwinnen. Zo worden wilde katten vaak verward met (verwilderde) huiskatten, die afgeschoten mogen worden door jagers. Gelukkig mag er daarom in Zuid-Limburg niet meer gejaagd worden op katten. Een ander risico is kruising met (verwilderde) huiskatten. Dit kan leiden tot een bedreiging voor hun genetische integriteit. Tenslotte moeten wilde katten eerst de veilige bosomgeving verlaten en allerlei drukke wegen oversteken om in Nederland aan te komen. Eén van deze wegen is de E40 in België (Luik-Aken). Dit onderzoek heeft alle oversteekmogelijkheden van de E40 in België (Luik-Aken) in kaart gebracht. Alle oversteekplaatsen zijn opgemeten, beschreven en gefotografeerd. Verder is op een aantal locaties in het westelijke gedeelte camera's geplaatst, om te kijken welke dieren en mensen er gebruik van maken. In totaal zijn er 56 oversteekmogelijkheden gevonden, waarvan 12 bruggen, 10 onderdoorgangen en 34 duikers. Bij twaalf oversteekmogelijkheden zijn camera's met geurstokjes geplaatst, die in totaal 23.700 filmpjes en 1.332 foto's hebben opgeleverd. Er zijn geen wilde katten opgenomen. Huiskatten komen op bijna alle locaties voor. Verder gebruiken vossen vooral duikers en het ecoduct, terwijl dassen voetgangerstunnels gebruiken.

Bruggen lijken het minst geschikt voor wilde katten om de snelweg over te steken, vooral door het drukke verkeer. Onderdoorgangen die met name door voetgangers gebruikt worden lijken vooral voor nachtdieren zoals wilde kat en das geschikter. Duikers zijn vaak gelegen op plekken waar weinig mensen komen en lijken daardoor geschikt te zijn om veilig de snelweg over te steken. De oversteekplaatsen zijn momenteel alleen voor mensen ingericht. Echter, door een aantal aanpassingen zouden sommige oversteekplaatsen (nog meer) gebruikt kunnen worden door wilde katten en andere diersoorten. Zowel bij onderdoorgangen voor voetgangers als bij duikers zou meer vegetatie en beschutting een verbetering geven. Verder zouden er loopplanken kunnen worden geplaatst in (grote) duikers, die (tijdelijk) water bevatten. Daarnaast is het belangrijk om hekken te plaatsen langs de snelweg, om direct oversteken te voorkomen. Rasters kunnen geplaatst worden om dieren naar de oversteekmogelijkheden te begeleiden. Concluderend, er zijn verschillende oversteekmogelijkheden voor wilde katten bij de E40 in België (Luik-Aken). Echter is een aantal aanpassingen noodzakelijk om de effectiviteit van deze oversteekmogelijkheden te verbeteren. Hierdoor heeft de wilde kat een grotere kans om succesvol terug te keren naar Nederland.

3. Introduction

In the Netherlands various animal species have been extinct in the past. Recently, several animal species are making their comeback (Deinet et al., 2013). Some of these species are returning with the help of reintroduction programmes. One of these programmes has released 30 otters between 2002 and 2008 (Koelewijn et al., 2010). In order to make a comeback successful, causes of the previous extinction have to be erased. Otters have been hunted severely and have been killed by cars frequently. Currently, otters are legally better protected and otter tunnels are built in some regions. The current estimated otter population consists of 100 individuals and is still growing. Another species that has returned with the help of humans is the wisent. These large herbivores have been extinct as a result of hunting, competition with domestic livestock and loss of suitable habitat (Tokarska et al., 2011). At the moment, in Europe many farmers abandon their land and agriculture is intensified at a smaller surface, which leads to an increase of suitable habitat for the wisent and other animals. Wisents are now grazing at the Kraansvlak and may be reintroduced in more areas. Other animals are making a comeback on their own. For example, white-tailed eagles have returned in 2004 and have started reproducing in 2006 in the Oostvaardersplassen. These raptors have been erased due to various factors, including hunting and accumulation of chemicals (Lumeij & Westerhof, 1993). Nowadays, more rules about the use of chemicals are imported, giving raptors a better chance of survival. Furthermore, wolves are expected to enter the Netherlands in the upcoming years, as a consequence of the increasing wolf population in neighbouring countries such as Germany. Wolves have been hunted severely in the past, leading to a complete disappearance in the Netherlands. The wolf is now protected by the European commission and Dutch law, making a comeback to the Netherlands possible. Also the European wildcat (*Felis silvestris silvestris*) has started its comeback to the Netherlands (figure 1). In the past this medium-sized carnivore occurred in the Netherlands at least until the Roman Period (Canters et al., 2005). Deforestation and hunting have led to a major reduction of wildcats in Europe and even a complete disappearance in the Netherlands (Klar et al., 2008).

Figure 1. Photo of the European wildcat (photo from Flickr).

In the last century several wildcat observations are already reported. However, only one of these reports is confirmed, which is a dead wildcat in 1999 near Nijmegen (Canters et al., 2005). The last couple of years more wildcat observations are confirmed, namely in Vaals (2002), in Epen (2006), twice in other parts of South-Limburg (2013) and in Vijlen (2014). Moreover, in June 2014 a wildcat is caught in Vijlen and equipped with a GPS collar. The wildcats probably originate from wildcat populations that are growing in the Eifel in Germany and in the Ardennes in Belgium (Stubbe & Stubbe, 2002).

Although there are some recent observations of wildcats in the Netherlands, for a real comeback there are still some threats, such as hybridisation risk with domestic cats and being killed by traffic or by hunters (Pierpaoli et al., 2003; Klar et al., 2009). In Addition, wildcats have to leave the relative save forest and cross multiple human structures, exposing themselves to all kinds of risks. One of the largest risks is major roads. Wildcats can be killed trying to cross these roads. For example, in one study 12 wildcats were found dead on a motorway in Germany during 26 months (Klar et al., 2009).

There are different ways animals can cross a road, including via crossing structures over or under a road and direct crossing on the road surface (figure 2). It is known that various animal species use non-wildlife crossing structures such as bridges, tunnels and culverts, which are built for traffic, pedestrians or drainage (Ng et al., 2004; Mata et al., 2005 & 2008). Whether wildcats use crossing structures and which types they prefer is still largely unknown. There are some studies that have showed that wildcats use crossing structures. For example, in Germany wildcats have used two of nine forestry roads 17 times in five months for crossing large roads (Hartmann et al., 2013). The research in Germany by Klar et al. (2009) indicates that wildcats prefer big open-span viaducts to cross a road. Most wildcats in this research have used a viaduct if it was situated in their home range and have crossed mainly between 18:00 and 6:00 when traffic was low (figure 3). Small local roads with low traffic have been crossed regularly and do not seem to act as a real obstacle. Other over- and underpasses have been used less frequently in this research, with forest overpasses as least preferred structure. In Spain wildcats seem to prefer passages in scrubland or farmland, with cover in their entrance and low human disturbance (Rodriguez et al., 1997). However, other studies have not found any wildcats using crossing structures (Ascensao & Mira, 2007; Grilo et al., 2008).

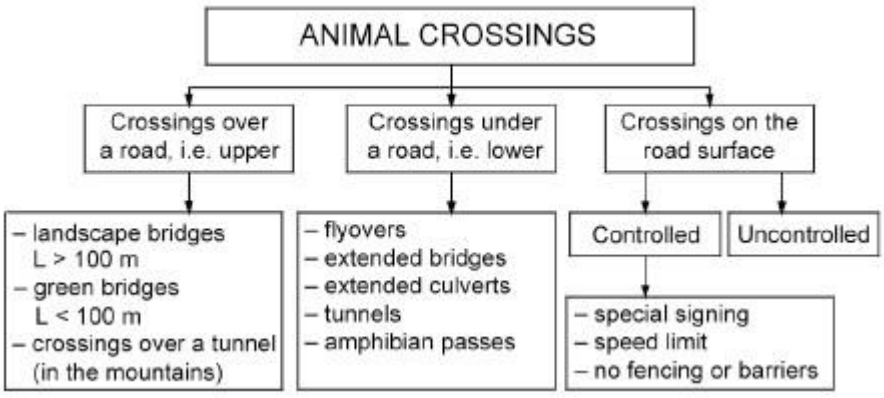

Figure 2. Scheme of animal crossings (figure from Beben, 2012).

Several factors influence the crossing behaviour of wildcats, such as human disturbance, landscape features and design of crossing structures. Human disturbance on and near a crossing structure will probably (negatively) influence wildcats, since this is the case with other carnivores (Clevenger & Waltho, 2000; Clevenger & Waltho, 2003). Also, landscape features influence the effectiveness of crossing structures for carnivores. For example, vegetation cover in or near crossing structures seems to be important, as well as surrounding habitat (Grilo et al., 2008). Other important factors are the width of the structure and the specific design (Mata et al., 2008). Every carnivore species seems to have other specific preferences. For example, wolves and grizzly bears favour short crossing structures which are high and wide, while black bears and cougars prefer more constricted structures (Clevenger & Waltho, 2005). Furthermore, there seems to be a relationship between the size of the animal and the size of the crossing structure. Small culverts are often used by small mammals, while larger over- and underpasses are regularly used by foxes and wolves (Mata et al., 2005). How often a road is used by cars is also very important. Busy roads are not frequently crossed directly, while at low traffic roads animals are less afraid to cross, leading to a high mortality risk (Van Langevelde et al. 2009).

If wildcats indeed travel from the Eifel or Ardennes to the Netherlands, one of the major roads they are very likely to cross is the highway E40 in Belgium (Liège-Aachen). This highway has only one ecoduct for wildlife crossing, near Welkenraedt. The ecoduct is built a couple of years ago to compensate for the construction of a new railway (parallel to the E40 highway) through the Grunhaut forest. It is a large open-span overpass covered with vegetation.

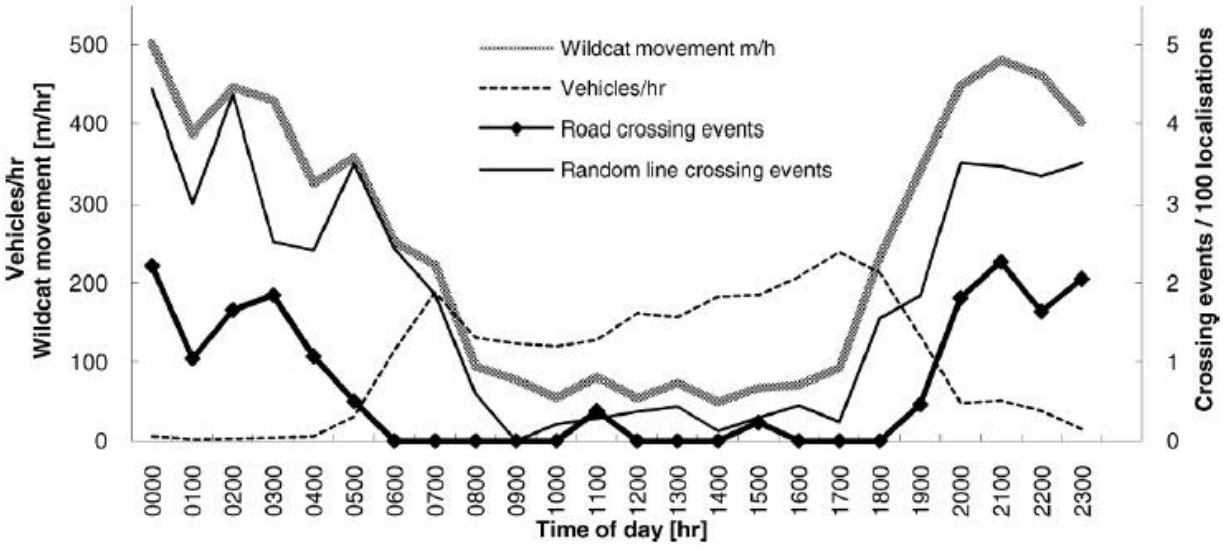

Figure 3. Crossing events of wildcats in a study in Germany (figure from Klar et al., 2009). Wildcats have crossed mainly between 18:00 and 6:00, when traffic was low.

The question is whether there are other possible crossing structures along the E40, which could increase the chance of a successful comeback of wildcats to the Netherlands. Therefore, in this research crossing structures of the highway E40 (Liège-Aachen) in Belgium have been investigated. First of all, the locations of the crossing structures are determined and measurements and photos are taken. Secondly, at some of the crossing structures cameras are placed, to determine if wildcats or other animals are using it. At the end of the report suggestions will be given for adjustments, necessary for wildcats being able to cross the E40.

Wildcats travelling from the Eifel or Ardennes to the Netherlands will search suitable habitat to establish a territory. The size of the home range differs between males and females, with males occupying larger areas. For example, in Portugal the average home range area of males is 13,71 km^2 and of females 2,28 km^2 (Monterroso et al., 2009). Generally the territory contains a patch of forest, in which they can hide during the day (Wittmer, 2001). This is confirmed by a study in Germany in which 75% of male and 91% of female radio locations are in the forest (Klar et al., 2008). However, in a Mediterranean area wildcats prefer a scrub-pastureland mosaic landscape over forest (Lozano et al., 2003). This implicates that hiding places and prey species availability may be more important than vegetation type. This hypothesis is supported by a study in Germany, in which a model is developed that shows that distance to watercourse is important, most likely because riparian areas provide shelter and prey availability is high (Klar et al., 2008). Generally, deadwood structures near forest edges or shelter structures in scrublands are used as hiding places (Lozano et al., 2003; Jerosch et al., 2010). Additionally, studies in Spain and Portugal confirm that prey availability is extremely important and scrubland mosaics are preferred over forest (Monterroso et al., 2009; Lozano, 2010). Wildcats are facultative specialists which prey on rabbits and other small mammals. In Northern European countries such as Germany the main prey species are often mice such as bank vole, while in more Southern countries like Spain wildcats prefer rabbits when present (Malo et al., 2004). Another research analysed 15 studies and shows that small rodent consumption is negatively related to rabbit consumption or presence (Lozano et al., 2006). It also states that if diet patterns are examined, it is crucial to determine the alternative prey availability. In addition, low human disturbance is key for a suitable habitat. The territories in a study in Germany are generally 900 meters away from villages and 200 meters from single houses and roads (Klar et al., 2008). Whether low human disturbance is primarily caused by humans themselves or by other factors such as less suitable habitat is debatable.

4. Methods

To investigate the possibility of wildcats crossing the highway E40 in Belgium(Liège-Aachen), crossing structures were examined.

Study area

The highway E40 is an important large road, which starts at the coast of France (Calais) and goes all the way through Europe to the border of China. For this research the part from the ecoduct near Welkenraedt until the German border was studied (17 km, figure 4). The traffic intensity of this section is depicted is table 1. This information is provided by Didier Antoine from Service public de Wallonie. The highway intersects three relative small forests: Grunhaut forest, Buchenbusch and Landwehring. Welkenraedt and Eupen are villages in the area. Furthermore, some smaller villages are located nearby such as Baelen, Lontzen, Walhorn, Eynatten and Raeren. Parallel to the highway is a railway. In the study area this railway is located next to the highway from the ecoduct until some metres before the Buchenbusch. Fences are present at both sides of the railway track. Unlike the highway, where no fences are present.

Crossing structures

All crossing structures were constructed for human use, except for the ecoduct. In preparation of the fieldwork, the map of the study area was examined with Google Maps and Google Earth. Next, the exact location of all crossing structures was determined in the field with the help of the GPS device Garmin. Photos of all crossing structures and the neighbouring area were taken. In addition, the length, width and height of the structures were measured with a ruler, by counting footsteps or by measuring with a tool in Google Earth. For some structures it was impossible to take measurements, for instance culverts with a fence in front of it. For every structure was written down information about the berm, vegetation, lighting, human disturbance, pavement and road markings. Moreover, a general description was noted with for example information about the environment. This fieldwork took place from 28 January until 4 March 2014.

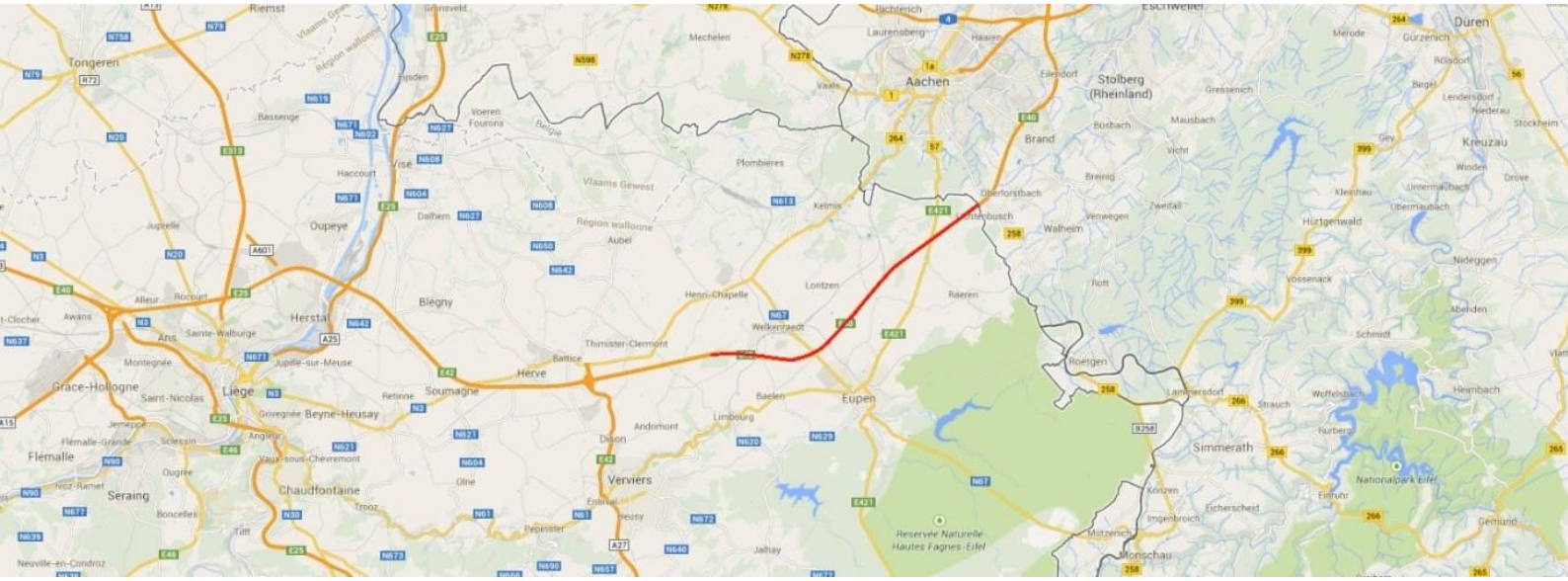

Figure 4. Map of the study area. The red line represents the section of the highway E40 that was studied.

Cameras

To determine if wildcats or other animals were crossing the highway via crossing structures, at several locations cameras were placed. In order to place a camera, permission from the owner of the structure was needed. The forest manager of the western side of the study area (Yves Pieper) gave permission to place cameras in his region. Unfortunately, the forest manager of the eastern side (Pascal Mertens) could not give permission to place cameras, due to recently changed privacy rules. Therefore, cameras were placed only at the western part of the study area, from 4 February until 23 April 2014.

Two cameras were placed at the ecoduct for eleven weeks (table 2). At the rest of the crossing structures one camera was placed for a shorter period, varying from one week (location 23) to ten weeks (location 16). Ten Bushnell model 119438 and two Reconyx cameras were used. The Bushnell cameras made movies of ten seconds each, while the Reconyx cameras took photos (three per second). Both cameras were protected by a locked metal body and were pinned to a tree with a cordless drill. Cameras were directed at the crossing structure and were placed at hidden spots to prevent theft. If a camera was detected by humans or was located very close to paths human often used, cameras were relocated or removed. One camera was stolen in the last week at location 19. Vegetation in front of the camera was (partially) removed to prevent false triggers. All cameras were mostly checked every week (table 3), whereby batteries and SD memory card were replaced. All Bushnell cameras were set at a high infrared and sensor setting. At some locations these settings were changed to medium or low, depending on the circumstances. The interval was set at one second. The sensor of the Reconyx cameras was instituted at high and the night mode on balanced or high quality.

To attract wildcats, four different lure sticks were placed in front of the camera: nepeta, valerian, fish oil and peanut butter. The first two were self-made by adding salad oil to nepeta or valerian powder, while the other two were bought at a store. The substances were applied at four small branches from the surrounding environment. In the first five weeks only nepeta and valerian were used.

Table 1. Traffic intensity at sections of the highway E40 in the study area (number of cars per time frame). Numbers are derived from 2013, by Service public de Wallonie.

Section	**6-22h**	**22-6h**	**0-24h**
Thimister-Clermont [37bis] - Eupen-Welkenraedt [38]	24.941	3.245	28.186
Eupen-Welkenraedt [38] - Eynatten [39]	20.355	3.114	23.469
Eynatten [39] - Lichtenbusch [40]	22.394	2.853	25.247

Table 2. The number of weeks cameras were present and the type of camera (B=Bushnell or R=Reconyx) at each crossing structure.

Crossing structure #	Weeks #	B/R
16	10	B
17	11	B & R
18	6	B
19	3	B
21	4	B
22	3	B
23	1	B
24	3	B
25	4	B
26	3	B
27	4	R
45	4	B

Table 3. The date of each time cameras were checked and the number of days between two check-ups.

Week #	Date	Days #
1	4-2-2014	7
2	11-2-2014	2
3	13-2-2014	12
4	25-2-2014	7
5	4-3-2014	14
6	18-3-2014	8
7	26-3-2014	7
8	2-4-2014	6
9	8-4-2014	8
10	16-4-2014	7
Total		**78**

Data analysis

Movies from the Bushnell cameras were watched with Windows or VLC media player. Movies and photos were divided into the following categories: Domestic cat, Unknown cat, Wildcat, Human, Badger, Bird, Deer, Dog, Fox, Horse, Lagomorph, Mice, Small mustelid, Squirrel, Placing camera, Nothing, Unknown animal and Don't work. All movies of possible wildcats were checked by Anke Brouns, Jaap Mulder and René Janssen. In some cases it was not possible to determine if a cat was a wildcat or not (category Unknown cat). All movies and photos with human activity such as pedestrians, bikers and cars were placed in the category Human. If human activity took place together with animals such as dogs, the movie or photo was only placed in the animal category (in this case Dog). Furthermore, movies and photos that were taken during the placement of the cameras and lure sticks were divided in the category Placing camera. The category Unknown animals consists of animals that could not be identified. And finally, some movies were not possible to open and were placed in the Don't work category.

To differentiate between wildcats and domestic cats on videos and photos, several characteristics were considered based on previous research (Canters et al., 2005). First of all, wildcats are generally larger and more heavily built than domestic cats. Secondly, the dorsal stripe stops at the end of the back of wildcats, while domestic cats often have a dorsal stripe on their tale too (figure 5). At the end of the tail wildcats have several black rings and a black blunt tip. The tail of wildcats is often bushy, in contrast with the more pointed small tail domestic cats have. Furthermore, the stripes on the coat of a wildcat are usually fainter than of domestic cats. Another important feature is the hind feet. Domestic cats have completely black hind feet, while wildcats have a more irregular pattern. Hybrids are more difficult to detect, since they can have one or more wildcat characteristics. Therefore, if not all wildcat features were visible on videos or photos cats were divided into the Domestic or Unknown cat category.

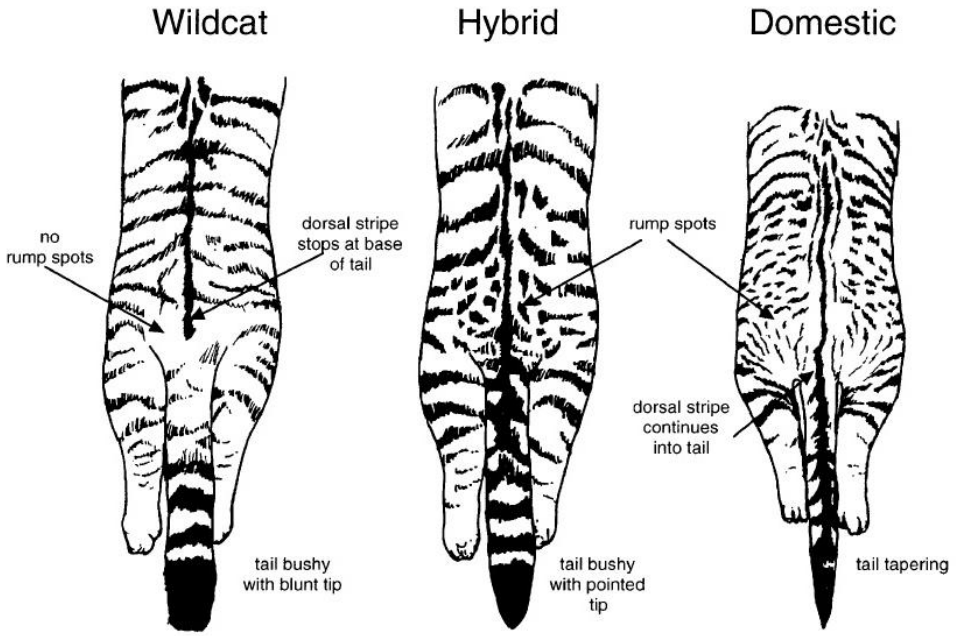

Figure 5. The different characteristics of wildcats, hybrids and domestic cats (figure from Canters et al., 2005).

The success rate was calculated for all crossing structure types by the formula: 1-(category “Nothing”/(total recordings - category “Don’t work”))*100. This was done for the overpasses, underpasses, culverts and ecoduct.

Several tests were performed to check for correlations. All datasets were not normally distributed. Multiple Spearman rank tests were performed to check for a correlation between the number of human events and the number of all animal events, the number of wild animal events (horse, dog and domestic cat were excluded), the number of events of fox, badger, deer, small mustelid, lagomorph and squirrel taken together, the number of fox events and the number of badger events. Also a Spearman rank test was performed to check for a correlation between the number of fox events and the number of badger events.

It was not possible to use the collected data for further (comparison) analysis, because of multiple reasons. First of all, at some structures cameras were located for several weeks, while at others cameras had to be removed after one week (table 2). Also, at some crossing structures many false triggers were recorded, leading to a full SD memory card or empty batteries after only one day. Consequently, animals that may have used the structure to cross the highway during these days are not recorded. Another important note is that in some cases animals were sitting in front of the camera for a long time, leading to a high number of videos. Individual recognition of animals was often not possible, so no estimations about the number of animals (within one species) using a structure can be made.

ArcGIS 10 was used to create maps of the study area to show at which crossing structures unknown cats, foxes and badgers were recorded. Furthermore, a map was made to show the human occurrence per crossing structure. First, human occurrence was divided into three classes: 0-100, 101-500 and more than 500 total recorded events of humans. Secondly, human occurrence was corrected for the number of weeks cameras were placed at a crossing structure, by dividing the total number of human events at each structure by the number of weeks cameras were placed at each structure. Again three categories were made: 0-25, 25-100 and more than 100 events per week. After this correction, all structures stayed in the same category.

5. Results

Crossing structures

At the 17 km long highway section, 56 crossing structures are located. The structures can be divided into three categories: overpass (12 units, figure 6), underpass (10 units, figure 7) and culvert (34 units, figure 8). The length, width and height are measured or estimated for all structures (table 4). Some structures have one large over- or underpass for the highway and the railway together, while others have a separate structure for the highway and railway. For most culverts it is unclear whether they reach the end of the highway or end up somewhere else. Photos of all crossing structures are depicted in appendix 3.

Figure 6. An example of an overpass (crossing structure 23).

Figure 7. An example of an underpass, located in the Buchenbusch (crossing structure 1).

Figure 8. An example of a culvert (crossing structure 2).

Crossing structure #	O/U/C	Length (m)	Width (m)	Height (m)
1	U	77,80	2,99	3,78
2	C	?	0,30	0,32
3	C	?	0,30	0,32
4	O	87	11	?
5	O	87	10	?
6	C	?	?	?
7	O	80	9	?
8	C	?	?	?
9	O	95	8	?
10	O	104	14	?
11	U	*27*	*8,40*	5
12	C	?	*1*	*1,20*
13	C	?	*1*	*0,90*
14	O	*64,80*	*8,10*	?
15	U	*28,80*	3	*3,50*
16	U	*100,20*	5	*4,50*
17	O	87	30	?
18	U	*29,40*	3	*4*
19	U	*28,80*	*10,20*	*5*
20	C	?	0,25	0,22
21	C	?	0,20	0,22
22	O	*76,80*	*9,60*	?
23	O	*111,60*	*7,20*	?
24	U	*32,40*	9	6
25	C	?	?	?
26	U	*28,20*	3	*5*
27	C	?	0,21	0,21
28	O	90	26	?
29	C	?	0,30	0,30
30	C	?	?	?
31	C	?	?	?
32	C	?	?	?
33	C	?	?	?
34	O	*69*	10,50	?
35	O	*66*	*7,80*	?
36	U	*27*	3	*3,60*
37	C	?	0,35	0,35
38	C	?	0,28	0,28
39	C	?	0,28	0,28
40	C	?	1	1,35
41	C	?	0,40	0,40
42	C	?	0,31	0,31
43	C	?	0,30	0,30
44	C	?	0,70	0,70
45	U	?	?	?
46	C	?	*0,27*	*0,16*
47	C	?	0,27	0,16
48	C	?	?	?
49	C	?	?	?
50	C	?	?	?
51	C	?	?	?
52	C	?	?	?
53	C	?	1,80	2
54	C	?	0,30	0,20
55	C	?	0,30	0,30
56	C	?	*4*	*1*

Table 4. All crossing structures in the study area, divided in three categories: overpass (O), underpass (U) and culvert (C). The length, width and height are depicted. Italic numbers are estimated based on counting footsteps, underscored numbers are estimated based on measurements with a tool in Google Earth and other numbers are measured in the field with a ruler. Question marks mean that it was impossible to take measurements.

Several characteristic of all crossing structures are examined, such as information about the berm, vegetation, lighting, human disturbance, pavement and road markings. First of all, many overpasses have a small berm, mostly for pedestrians. Only some underpasses have a berm, while culverts do not have such a thing. All crossing structures have no vegetation on their structure, except the ecoduct and a large underpass. These special overpass and underpass are full of grasses, shrubs and small trees (figure 9 and 10). Furthermore, most structures have no lighting, except street lamps of the highway or other nearby roads. However, one overpass and some underpasses do have lamps at their structures. Nevertheless, recordings from one overpass show that the lamps at this structure are not switched on for the entire night. All crossing structures have some kind of human disturbance in their surrounding environment. For example, most overpasses are used frequently by cars. Culverts are generally situated in areas with less human disturbance, often at slopes covered in shrubs and trees which are not directly accessible to people. Many underpasses are mainly used by pedestrians and bikers. All crossing structures are paved, except a large underpass which is only partially paved (crossing structure 45, figure 10). In the middle of this underpass is a railway located. The pavement of the ecoduct is not visible anymore, due to the vegetation cover (figure 9). Finally, most crossing structures do not have any road markings, except two large overpasses and one large underpass. An overview of all information about the crossing structures can be found in appendix 1.

Figure 9. The ecoduct is full of grasses and some shrubs and small trees (crossing structure 17).

Figure 10. A large underpass with in the middle a railway (crossing structure 45).

Cameras

Ten Bushnell cameras have made in total 23.700 movies of ten seconds. The two Reconyx cameras have made 1.332 photos. This means that in total 25.032 events are recorded. All movies and photos are divided into the following categories: Domestic cat, Unknown cat, Wildcat, Human, Placing camera, Dog, Horse, Badger, Bird, Deer, Fox, Lagomorph, Mice, Small mustelid, Squirrel, Unknown animal, Don't work and Nothing. The number of movies or photos at each structure does not say much about the number of recorded individuals, but rather gives an indication which species occur at a structure. Moreover, some animals have been in front of the camera but did not really use the structure to cross the highway. For example, some domestic cats were attracted to the lures sticks in front of a culvert, but did not use the culvert. In addition, in many movies is nothing to see (category Nothing, 18.955 events). This is mostly caused by false triggers and the relative long reaction time of the camera.

There seems to be a rather large difference between animal species recorded by overpasses, underpasses and culverts (table 5). The ecoduct is shown separately, because it differs greatly from other overpasses. Only humans and domestic dogs and cats use overpasses (except the ecoduct). At underpasses more animal species are recorded on the camera, such as birds, mice and badgers. Most of these animals do not really use the underpasses to cross the highway, but are recorded in front of the structure. However, badgers do really use the underpasses.

Table 5. The total number of events (movies and photos together) for overpasses, underpasses, culverts and the ecoduct and the success rate in percentage.

Category	**Subcategory**	**Overpasses (2)**	**Underpasses (6)**	**Culverts (3)**	**Ecoduct (1)**	**Total**
Cats	**Domestic cat**	9	55	293	106	**463**
	Unknown cat	0	3	0	13	**16**
	Wildcat	0	0	0	0	**0**
Humans	**Human**	1.039	1.638	23	61	**2.761**
	Placing camera	59	334	133	312	**838**
Domestic animals	**Dog**	10	391	0	30	**431**
	Horse	0	32	0	8	**40**
Other animals	**Badger**	0	13	0	1	**14**
	Bird	0	100	189	6	**295**
	Deer	0	0	0	45	**45**
	Fox	0	9	56	49	**114**
	Lagomorph	0	7	0	29	**36**
	Mice	0	244	260	304	**808**
	Small mustelid	0	0	14	0	**14**
	Squirrel	0	4	0	0	**4**
	Unknown animal	0	2	3	14	**19**
Other	**Don't work**	12	96	9	62	**179**
	Nothing	1.084	9.640	543	7.688	**18.955**
Total		**2.213**	**12.568**	**1.523**	**8.728**	**25.032**
Success rate %		50,75	22,71	64,13	11,29	23,73

Culverts are the only structure where small mustelids are recorded. Furthermore, foxes have used one culvert multiple times to cross the highway. Most animal species are found at the ecoduct. For example deer, foxes, mice and rabbits (lagomorphs). Many of these animals seem to use the ecoduct to cross the highway.

The success rate of recordings also differs greatly between the crossing structure types (table 5). The ecoduct has the lowest success rate (11,29%), which is mainly due to false triggers of moving vegetation. The low success rate of underpasses (22,71%) can partly be explained by cars at one underpass (crossing structure 24), which trigger the camera but have already passed when the camera starts recording. At another underpass (crossing structure 16) many false triggers are recorded because of moving vegetation and/or an impaired camera. At overpasses the success rate is 50,75%. Many cars have triggered the camera, but traffic is quite high which often leads to a recording of a different car passing by. The highest success rate is found at culverts (64,13%), which is probably a consequence of low human occurrence and the absence of high vegetation and wind, which can cause false triggers.

Wildcats

No wildcats are recorded. Some cats have some characteristics of wildcats, such as rings at the tail and a black tip. However, not all characteristic are present or clearly visible (figure 11). For example, the coat of a cat recorded on the ecoduct has many conspicuous stripes, while wildcats often have more fainted stripes. Domestic cats are recorded at all crossing structures, except one. They seem to be really attracted to the lure sticks, sometimes rubbing against it for quite a while or licking the fish oil. Moreover, other animals such as foxes, deer and dogs also seem to be attracted to the lure sticks.

Figure 11. Photo (left) and screen shot (right) of unknown cats recorded at the ecoduct.

Other small predators

This study has not recorded any wildcat using crossing structures, but other small predators such as fox and badger are recorded (table 5). At the ecoduct foxes are regularly recorded (in total 49 events). No foxes are recorded at other overpasses and only nine events of foxes are recorded at underpasses. One time a fox has entered a long underpass situated at the edge of the Grunhaut forest, which is mainly used by pedestrians. However, after a couple of seconds the fox returned, so it has not really crossed the highway. The other videos of foxes are recorded at a large underpass with a railway track in the middle. It is hard to determine if these foxes have really crossed the highway or stayed at one side of the highway. Furthermore, cameras are placed at three culverts, which are not located in a forest (number 21, 25 and 27). At the first culvert 45 movies of foxes are recorded, whereby in many cases foxes went in or out the culvert. It is hard to see how many individuals use the culvert, but it seems to be more than one. One of four photos of foxes at the second culvert looks like a fox running out of the culvert. At the last culvert seven movies of foxes are recorded, but in none of these movies foxes seem to go in or out the culvert. Another small predator that is recorded is the badger. One badger is recorded at the ecoduct. Furthermore, two underpasses which are mainly used by pedestrians are used by badgers in 13 events. One of these underpasses is situated at the edge of the Grunhaut forest, the other is not close to a forest. No badgers are recorded at culverts.

Correlations

Despite large differences between the number of weeks cameras have been placed at crossing structures, tests have been performed to check for correlations between different categories. First of all, no correlation is found between the number of human events and the number of animal events at crossing structures (Spearman rank correlation: rs = -0,19, N = 12, p = 0,56). However, a negative trend is found when domestic animals are excluded (Spearman rank correlation: rs = -0,50, N = 12, p = 0,10). Similarly, a negative trend is found for the relation between the number of human events and the number of events of fox, badger, deer, small mustelid, lagomorph and squirrel taken together (Spearman rank correlation: rs = -0,51, N = 12, p = 0,09). Also a negative trend is found for the number of human events and the number of fox events (Spearman rank correlation: rs = -0,55, N = 12, p = 0,07). No significant correlation is found between the number of human events and the number of badger events (Spearman rank correlation: rs = 0,27, N = 12, p = 0,40). Finally, no significant correlation is found between the number of fox events and the number of badger events (Spearman rank correlation: rs = -0,11, N = 12, p = 0,73).

GIS-maps

Several maps of the study area are made with ArcGIS 10. The first map gives an overview of all crossing structures (figure 12). A distinction is made between overpasses, underpasses and culverts. In all three forests in the study area multiple culverts are situated. Furthermore, in the Grunhaut forest is an ecoduct located and two underpasses for pedestrians at the edges of the forest. In the Buchenbusch is one underpass for pedestrians, while in Landwehring only one overpass for cars is present. Parallel to the highway E40 is a railway track located, from the western side until the Buchenbusch. Another railway track crosses the highway around Welkenraedt as an underpass (crossing structure 45) and later on as an overpass (crossing structure 34).

At all crossing structures domestic cats are recorded, except at crossing structure 23. However, the camera at this location has only worked for two days. Afterwards, the SD-card was full, due to many recordings of cars and false triggers. At three locations domestic cats have been recorded 50 or more times (crossing structures 17, 21 and 27). Unknown cats are recorded at three locations (crossing structures 16, 17 and 18, figure 13). Foxes are recorded at six crossing structures (number 16, 17, 21, 25, 27 and 45, figure 14). Finally, at three crossing structures badgers are recorded (number 17, 18 and 26, figure 15).

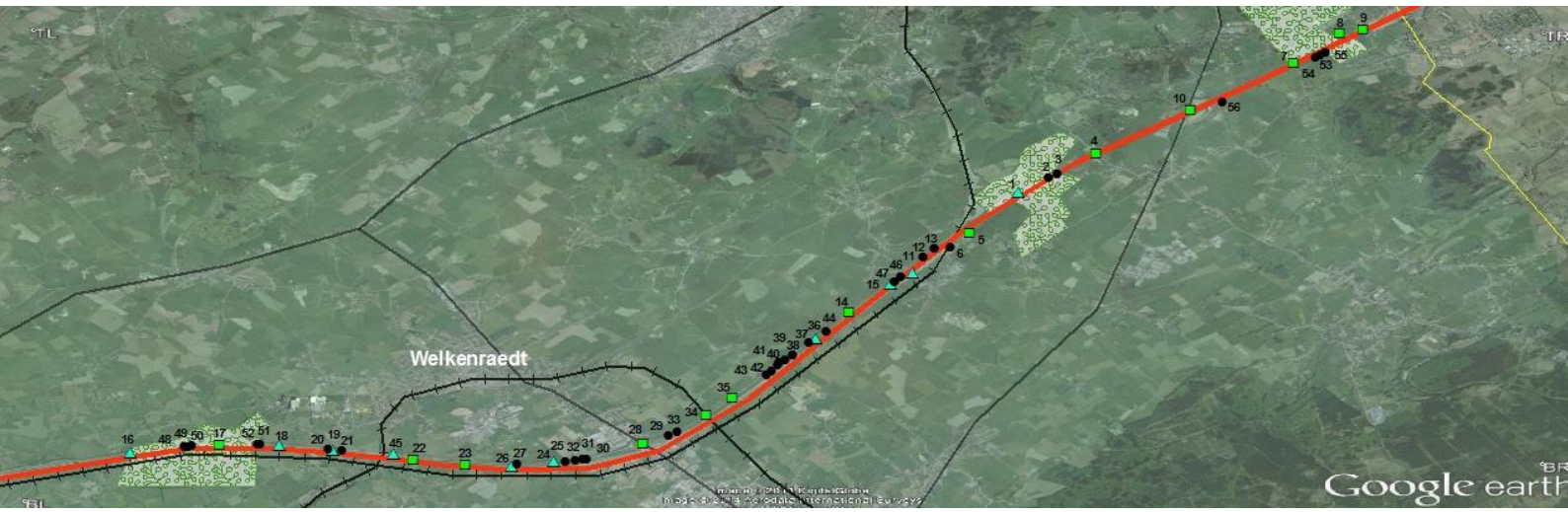

Figure 12. Overview of all crossing structures. Green squares are overpasses, blue triangles underpasses and black circles culverts. The red line is the highway E40 and black lines are smaller roads nearby. Black lines with stripes are railways and the yellow lines represents the border with Germany. Three forests are situated in the study area, depicted in white with green leafs (from west to east: Grunhaut forest, Buchenbusch and Landwehring).

Figure 13. Overview of unknown cat occurrence. Red circles represent crossing structures where unknown cats are recorded. Black circles are crossing structures where no unknown cats are recorded. The red line is the highway E40. Black lines with stripes are railways. The other black line is a N-way. The Grunhaut forest is represented by the white with green leaves area.

Figure 14. Overview of fox occurrence. Red circles represent crossing structures where foxes are recorded. Black circles are crossing structures where no foxes are recorded. The red line is the highway E40. Black lines with stripes are railways. The other black line is a N-way. The Grunhaut forest is represented by the white with green leaves area.

Figure 15. Overview of badger occurrence. Red circles represent crossing structures where badgers are recorded. Black circles are crossing structures where no badgers are recorded. The red line is the highway E40. Black lines with stripes are railways. The other black line is a N-way. The Grunhaut forest is represented by the white with green leaves area.

Humans

At all 56 crossing structures photos or videos of humans are recorded. At some locations mainly cars are recorded and at others mostly pedestrians. Human occurrence can be divided into three classes: 0-100, 101-500 and more than 500 total events or 0-25, 25-100 and more than 100 events per week (figure 16). When corrected for the number of weeks cameras are placed at a crossing structure, all structures stay in the same category.

The highest human occurrence is found at an overpass (crossing structure 23) and an underpass (crossing structure 24) where traffic is very high. Crossing structures 18, 22 and 26 are in the middle category of human occurrence. The first two structures are underpasses which are regularly used by pedestrians, bikers and humans that are walking with their dog. Crossing structure 26 is an overpass, which is mainly used by cars. The lowest human occurrence is found at the other crossing structures (number 16, 17, 19, 21, 25, 27 and 45). These are underpasses, culverts and the ecoduct. Underpass 19 is probably used by cars quite often, but due to the camera set-up no cars are recorded. Therefore, this underpass has most likely a higher human occurrence than is shown in this study. Culverts are generally located at slopes which are not directly accessible to people. Therefore, human occurrence is very low near culverts.

Figure 16. Overview of human occurrence. The smallest green dots represent 0-100 total events of humans or 0-25 events per week. The small yellow dots show 101-500 total events of humans or 25-100 per week. The red large dots are more than 500 total events of humans or more than 100 events per week. The red line is the highway E40. Black lines with stripes are railways. The other black line is a N-way. The Grunhaut forest is represented by the white with green leaves area.

6. Discussion

This research focussed on the crossing possibilities for wildcats at the highway E40 in Belgium (Liège-Aachen). In total 56 crossing structures were found. All crossing structures were measured, described and photographed. At some structures cameras were placed, to determine if wildcats or other animal species were using the crossing structures.

Crossing structures

In total 12 overpasses, 10 underpasses and 34 culverts were found. The overpasses were frequently used by cars and therefore do not seem very suitable for animals to cross the highway. This is confirmed by the recorded events, given that only humans and domestic dogs and cats used overpasses (except the ecoduct). Also the negative trend between the number of human events and the number of wild animal events at crossing structures confirms this statement. Moreover, previous research shows that human use of crossing structures can negatively affect animal activity at crossing structures (Barrueto et al., 2013). Some underpasses were also mainly used by cars and for this reason neither seem very suitable for animals. However, other underpasses were generally used by pedestrians and thus appear more suitable. Especially the underpasses that have a separate tunnel for the highway and the railway track are appealing. These tunnels are not very long, exposing animals only for a short time. This is confirmed by the recorded events, which showed badgers using only relative short underpasses that were mainly used by pedestrians. Additionally, previous research shows that underpasses are more frequently used than overpasses (Beben, 2012). A possible explanation is that underpasses are more naturally integrated in the environment. Finally, most crossing structures in the study area were culverts, which were mostly situated at slopes with some shrubs and trees, not directly accessible to humans. Therefore, many of these culverts may be used regularly by animals to cross the highway. The negative trend between the number of human events and the number of wild animal events confirms this statement. In this study cameras were placed at three culverts. At all three culverts various animal species such as small mustelids were recorded, with at least one small mustelid running in and out one culvert. Small mustelids were not recorded at other crossing structures. However, for most culverts it was unclear whether they end up at the other side of the highway. Perhaps, some of the culverts are part of a larger drainage network. Animals that enter a culvert could cross the highway or may end up somewhere else. Previous research in Portugal has also found that many animal species use culverts, such as stone marten, hedgehog and fox (Ascensao & Mira, 2007). To sum up, short underpasses that are mainly used by pedestrians and culverts seem to be most suitable for wildlife crossing.

Wildcats

No wildcats were recorded in this study. Some cats did have some characteristic of wildcats, but other features were not present or not visible. The absence of wildcat recordings can be due to several factors. Firstly, all camera locations were close to human disturbance. The territories of wildcats in a German study are more than 200 meters away from single houses and roads (Klar et al., 2008). If this is also the case in the study area, all camera locations are not in suitable wildcat habitat. However, if wildcats start roaming in search for a new territory, they may cross less suitable areas. Especially if the pressure to migrate is high, wildcats may travel through areas with human disturbance which contain busy roads. Secondly, wildcats may travel from Belgium to the Netherlands via this highway, but the chance of recording travelling wildcats in such a short time (78

days) is quite low. Moreover, to determine if wildcats are present photos or videos are generally not enough. DNA-samples are necessary for confirmation. Previous research has obtained DNA by placing lure sticks to collect hair (Weber et al., 2008; Kéry et al., 2011). The current study did not have budget to analyse hair samples, but future research can collect hair to confirm wildcat presence. Even though no wildcats were recorded in this study, wildcats are still likely to cross this highway before entering the Netherlands. The wildcat that recently is caught in Vijlen and is equipped with a GPS collar has already crossed several busy roads (Anke Brouns, unpublished results). One of these roads is crossed via a badger culvert, while two other busy roads are crossed without crossing structures. Other countries such as Germany have also evidence of wildcats using crossing structures (Klar et al.,2009; Hartmann et al., 2013).

Individual differences

It is very likely that not all wildcats will react similarly to a highway. Some wildcats may be quite bold, trying to cross the road directly without any crossing structures. Others may cross only via specific crossing structures or may not cross at all. In Germany a study has followed several GPS collared wildcats and indeed has seen different reactions of wildcats to busy roads (Klar et al., 2009). Wildcats have taken a detour to reach a crossing structure or have turned around and did not cross at all. However, no analyses for individual behaviour has been performed. A research with stone martens in Portugal has investigated the individual differences of responses to a highway (Ascensao et al., 2014). Some stone martens seem to be attracted to the highway, while others are indifferent or avoid the highway. The different reactions may be (partly) caused by a difference in familiarity of the landscape. So individuals can act differently to a highway due to differences in personality and in differences in familiarity with the area. For example, wildcats that cross a highway for the first time may not be aware of the presence of crossing structures and can react differently than others that are better acquainted with the area.

Other small predators

This study did not recorded any wildcat using crossing structures, but other small predators such as fox and badger were recorded. At the ecoduct foxes were regularly recorded, probably often crossing the highway to go from one side of the forest to the other. No foxes were recorded at other overpasses and only nine events of foxes were recorded at underpasses. Furthermore, foxed used culverts regularly to cross the highway. This is in line with previous research, in which foxes have also used culverts frequently (Mata et al., 2005 & 2008). A negative trend was found for the number of human events and the number of fox events. This can partly be explained by the regular use of culverts by foxes, while humans cannot use culverts to cross the highway. Another small predator that was recorded is the badger. One badger was recorded at the ecoduct and several events of badgers are recorded at two underpasses. No badgers were recorded at culverts, perhaps because some culverts were too small for badgers or contained water. Badgers were also not recorded at overpasses, which is in agreement with previous research (Mata et al., 2005 & 2008). So even though no wildcats were recorded, other small predators did use several crossing structures. Wildcats may act similarly as foxes or badgers, which means that both underpasses and culverts could be suitable.

Ecoduct

Various animals were recorded at the ecoduct, such as fox, deer, badger, mice and rabbit. Therefore, it seems that this ecoduct is an effective crossing structure. However, although the last decade many ecoducts are built, often it is still unclear how effective these structures really are (Ovaskainen, 2013). First of all, in order to determine if an ecoduct is successful, it is important to establish for which purpose the ecoduct is built. For example, ecoducts can be built to prevent inbreeding in small isolated areas, to compensate for habitat loss or to connect different areas. Several studies have monitored the number of animals that have crossed an ecoduct in a certain period. Generally, crossing rates are calculated to determine if an ecoduct is regularly used. However, other studies show that in addition it can be crucial to identify individuals, because sometimes only a few individuals are using the structure but use it very frequently (Soanes et al., 2013). This can lead to overestimation of the effectiveness of an ecoduct.

Recommendations

All crossing structures in the study area are only built for human use, except the ecoduct. However, this study showed that nevertheless animals are using these structures to cross the highway. If some of the structures will be adjusted, the number of animals using the structures to cross the highway safely will most likely increase (appendix 2). This is the case in Poland, where after some adjustments the effectiveness of crossing structures has greatly increased (Brodziewska, 2006). In the current study, overpasses do not seem very suitable for animals, since traffic is high and vegetation is generally absent. Some underpasses are more suitable, especially the short ones that are mainly used by pedestrians and have shrubs and trees nearby. These underpasses may be used more often by animals if vegetation and shelter in and around these underpasses will be provided. Furthermore, many culverts seem to be suitable for wildlife crossing, especially those that are located in forests. Even the small culverts with only a diameter of 0,20 meter seem suitable, since they were used by foxes regularly. However, some culverts were full of mud or water. This can prevent wildcats to use culverts. A research in Portugal shows that mesocarnivores are less likely to use culverts that contain water more than 3 cm deep or covering more than 70% of the culvert (Serronha et al., 2013). Regular checking and maintenance of culverts can partly solve this. Of course, the function of most culverts is to drainage rainwater, which means that some culverts will (temporarily) contain water. Large culverts with water can be adjusted with a shelf, on which animals can walk. In the province Gelderland wildlife crossing structures are often used after similar adjustments (van Heukelum et al., 2012). In addition, the entrances of culverts can be covered with vegetation. This has a positive effect on the use of culverts in Portugal (Ascensao & Mira, 2007). The culverts at the Landwehring forest should get priority, because next to the culverts only one overpass for cars is present. Besides culverts is an underpass for pedestrians present in the Buchenbusch. The Grunhaut forest is the easiest forest to cross for animals, via the ecoduct. Overall, some adjustments such as providing more shelter and vegetation and placing shelves in (large) culverts can increase the use of crossing structures by animals, particularly the structures that are located at low human disturbance areas.

Not only the characteristics of the crossing structures are important, other factors also play a role in wildlife crossing. For example, in the study area no fences at the highway were present. This means that animals can enter the highway at all points, vulnerable to be killed by traffic. Fences can reduce this risk enormously. In Germany, wildcats killed on roads is reduced by 83% after wildcat fences are placed (Klar et al., 2009). However, wildcats can also be hindered by these fences. For example, some

wildcats have stopped crossing completely after fences are placed and only crossing structures can be used to cross the road (Klar et al., 2009). In addition, rasters should be placed around the crossing structures, to lead animals to the structures. If rasters are not an option, providing vegetation can be an alternative. Another important aspect is that humans are mostly active during the day, while wildcats and many other animals are more active between dusk and dawn. Therefore, underpasses that are mainly used by pedestrians are almost undisturbed at night. Traffic is also lower at night, even though at some busy overpasses cars are still present at night. Indeed, most recordings of (wild) animals were at underpasses, the ecoduct and culverts and between dusk and dawn, when human disturbance was low.

Method

This study tried to capture wildcats on cameras, by placing four different lure sticks (nepeta , valerian, fish oil and peanut butter). Unfortunately, no wildcats were recorded. This does not seem to be due to the method, because at almost all locations domestic cats were attracted to the lure sticks. Also many other animals were sniffing or licking the lure sticks, such as fox and deer. Previous research with valerian has different success rates. In one study wildcats do not seem to be attracted to valerian (Anile et al., 2012), while in other studies wildcats are attracted (Weber et al., 2008; Kéry et al., 2011). Recent research in the Netherlands and Belgium has also used valerian, but wildcats have not reacted very strongly on it (Janssen & Mulder, 2012 & 2013). If and how wildcats react to valerian may be influenced by gender, time period (mating period) or the way valerian is provided (oil or dry powder). Habituation may also play a role. Overall, lure sticks are a useful method to get the attention of animals such as wildcats and capture them on video or photo.

Obstacles

If wildcats will cross roads safely and arrive in the Netherlands, there are some other obstacles waiting for it. First of all, hunters are allowed to shoot feral cats. Wildcats can easily be mixed up with feral cats, so hunters may accidently shoot a wildcat. Fortunately, hunters are not allowed to shoot feral cats anymore in South-Limburg, to prevent wildcats being killed. Alternatives to control the disturbance feral cats cause are being developed (Lammertsma et al., 2011). Secondly, for a successful comeback reproduction is crucial. However, wildcats may interbreed with domestic or feral cats, which can threaten their genetic integrity. Feral and domestic cats are genetically equal, while they are genetically different from wildcats. Domestic cats originate from the African wildcat species. The number of domestic cats wandering in nature differs per region. For example, in South-Limburg the estimated domestic cat density is 2-5/km^2 in forests and 17-50/km^2 in agricultural landscape (Lammertsma et al., 2011). The magnitude of the hybridisation risk is still widely debated. High level of hybridisation is found in Scotland and Hungary (Beaumont et al., 2001; Pierpaoli et al., 2003), while in Belgium and Germany hybridisation levels are lower (Parent, 1974; Eckert et al., 2010). Hybrids seem to act at least partly as wildcats. For instance, wildcats and hybrids generally establish both large home ranges, in contrast to domestic cats (Germain et al., 2008). If there are no behavioural barriers between wildcats and hybrids, the hybridisation process can be accelerated. Feral cats and hybrids may also compete with wildcats for food and may transfer diseases (Lammertsma et al., 2011). The magnitude of these threats for wildcats is uncertain yet and may differ per region.

Conclusions

This research gives an overview of all crossing possibilities for wildcats and other animals at the highway E40 in Belgium (Liège-Aachen). Crossing structures can be divided into overpasses (12), underpasses (10) and culverts (34). No wildcats were recorded, in contrast to other species such as domestic cat, fox, badger and small mustelids. Domestic cats were recorded at almost all crossing structures. Badgers only used short underpasses with low traffic, while foxes most often used culverts to cross the highway. Both species were also recorded at the ecoduct, just like many other species such as mice, deer and rabbits. Some adjustments can be performed to make sure wildcats and other animals will use crossing structures more often, such as providing more vegetation and shelter in and around crossing structures, maintenance of culverts and placing shelves in large culverts. Fences at the highway and rasters leading to the crossing structures can also enhance wildlife crossings. Overall, the wildcat is making its comeback to the Netherlands and has, with a little help such as providing appropriate crossing structures, a good chance to succeed.

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8. Appendix 1 Overview of crossing structures

Table 1. Overview of all crossing structures. The following information is depicted: crossing structure number, date of inventory, GPS coordinates, type (O=overpass, U=underpass, C=culvert), length, width, height, road pavement, berm, vegetation on structure, road marking, lighting, human disturbance, general description and confirmation at the other side. Italic numbers are estimated based on counting footsteps, underscored numbers are estimated based on measurements with Google Earth and other numbers are measured in the field with a ruler. Question marks mean that it was impossible to take measurements.

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
1	28-1-2014	N 50 41.399 E 006 03.548	U	77,8	2,99	3,78	Yes	No	No	No	No	Pedestrians, hunters, horse riders	Tunnel in Buchenbusch, with culverts	Yes
2	28-1-2014	N 50 41.541 E 006 03.835	C	?	0,3	0,32	Yes	No	No	No	No	Pedestrians	In Buchenbusch, little water in it	?
3	28-1-2014	N 50 41.579 E 006 03.917	C	?	0,3	0,32	Yes	No	No	No	No	House and road nearby	In Buchenbusch, little water in it	?
4	28-1-2014	N 50 41.760 E 006 04.282	O	87	11	?	Yes	Yes, ±1,90m concrete both sides	No	No	No	Cars, bikers, pedestrians, house nearby	Below is culvert, next to open grass, entrance shrubs and trees	Yes
5	28-1-2014	N 50 41.012 E 006 03.078	O	87	10	?	Yes	Yes, ±1,90m concrete both sides	No	No	No	Cars, bikers, pedestrians, houses	Next to open grass, some shrub and trees	Yes
6	28-1-2014	N 50 40.878 E 006 02.899	C	?	?	?	Yes	No	No	No	No	Farmer, pedestrians	Little water in it	?
7	29-1-2014	N 50 42.625 E 006 06.152	O	80	9	?	Yes	Yes, concrete both sides	No	No	No	Cars, bikers	Edge of Landwehring, open grass, some shrub and trees, house nearby, not directly accessible for pedestrians	Yes
8	29-1-2014	N 50 42.904 E 006 06.580	C	?	?	?	Yes	No	No	No	No	House and footpath nearby	Water in it, edge of Landwehring, open grass, fence in front of it	Yes
9	29-1-2014	N 50 42.935 E 006 06.180	O	95	8	?	Yes	Yes, ±1,20m concrete both sides	No	No	No	Cars, bikers, pedestrians, houses	Lots of houses nearby, close to Landwehring, open grass, some shrubs and trees	Yes

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
10	29-1-2014	N 50 42.173 E 006 05.175	O	104	14	?	Yes	Yes, ±1,65m concrete both sides	No	Yes, arrow	Yes, street lights	Cars, bikers, pedestrians, houses, shops	Busy road (70km/h sign), close to houses and shops, some trees nearby	Yes
11	30-1-2014	N 50 40.637 E 006 02.548	U	*27*	*8,4*	5	Yes	Yes, ±2m concrete both sides	No	No	Yes, one lamp	Cars, bikers, pedestrians, houses	Next to railway underpass, many houses, fence at the highway, some shrubs and trees	Yes
12	30-1-2014	N 50 40.782 E 006 02.637	C	?	*1*	*1,2*	Yes	No	No	No	No	Pedestrians, horse riders	Water in it, fence in front of it, next to footpath in small forest, houses nearby	?
13	30-1-2014	N 50 40.867 E 006 02.753	C	?	*1*	*0,9*	Yes	No	No	No	No	Pedestrians, horse riders, employees of Infrabel	Water in it, next to footpath in small forest, fence in front of it, houses nearby	?
14	30-1-2014	N 50 40.252 E 006 01.941	O	*64,8*	*8,1*	?	Yes	Yes, ±1,4m concrete both sides	No	No	No	Pedestrians, horse riders	Next to farm, poorly maintained, next to small forest	Yes
15	30-1-2014	N 50 40.523 E 006 02.333	U	*28,8*	3	*3,5*	Yes	No	No	No	No	Pedestrians, horse riders	Open grass, shrubs and trees, nearby houses, with culverts	Yes
16	4-2-2014	N 50 38.929 E 5 55.126	U	*100, 2*	5	*4,5*	Yes	Yes, ±1,5m and ±0,5m concrete	No	No	No	Pedestrians, horse riders	Edge of Grunhaut forest, with culverts, open grass, shrubs and trees, houses nearby	Yes
17	4-2-2014	N 50 38.995 E 55.965	O	87	30	?	Yes, but not visible anym ore	Yes, ±2,3m footpath both sides	Yes, grass, scrubs and small trees	No	No	Pedestrians, horse riders	Ecoduct in Grunhaut forest, many grasses, shrubs and trees	Yes
18	4-2-2014	N 50 38.992 E 5 56.542	U	*29,4*	3	*4*	Yes	No	No	No	No	Pedestrians, horse riders, bikers	Edge of Grunhaut forest, with culverts, open grass, shrubs and trees	Yes

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
19	4-2-2014	N 50 38.950 E 5 57.045	U	*28,8*	*10,2*	*5*	Yes	Yes, ±2,65m concrete and ±1m ditch both sides	No	No	No	Pedestrians, horse riders, bikers, houses	With culverts, open grass, shrubs and trees, nearby houses,	Yes
20	4-2-2014	N 50 38.964 E 5 57.001	C	?	0,25	0,22	Yes	No	No	No	No	Pedestrians	Not much water in it, close to footpath, on slope with shrubs and trees, houses and open grass nearby	?
21	4-2-2014	N 50 38.952 E 5 57.133	C	?	0,2	0,22	Yes	No	No	No	No	Pedestrians	No water in it, close to footpath, on slope with shrubs and trees, houses and open grass nearby	?
22	4-2-2014	N 50 38.854 E 5 57.798	O	*76,8*	*9,6*	?	Yes	Yes, ±1,45m concrete and ±1m ditch both sides	No	No	No	Cars, bikers, pedestrians	Below is culvert, nearby houses, open grass, shrubs and trees	Yes
23	5-2-2014	N 50 38.804 E 5 58.296	O	*111,6*	*7,2*	?	Yes	Yes, ±1,5m concrete both sides	No	No	No	Cars, bikers, pedestrians	Open grass, some trees, houses nearby	Yes
24	5-2-2014	N 50 38.843 E 5 59.148	U	*32,4*	9	6	Yes	Yes, one side ±1,60m concrete, other side smaller	No	Yes, arrow	Yes, four lights	Cars, bikers, pedestrians	With culverts, construction work on railway tunnel, near highway exit, some shrubs and trees, open grass	Yes
25	5-2-2014	N 50 38.849 E 5 59.249	C	?	?	?	Yes	No	No	No	No	Pedestrians	Not much water in it, next to path with water, shrubs and trees, open grass	?
26	5-2-2014	N 50 38.796 E 5 58.748	U	*28,2*	3	*5*	Yes	No	No	No	Yes, two lights	Pedestrians, bikers	With culverts, next to railway underpass, power house, slopes with shrubs and trees, nearby open grass	Yes
27	5-2-2014	N 50 38.822 E 5 58.796	C	?	0,21	0,21	Yes	No	No	No	No		Little water in it, on slope with shrubs and trees, open grass nearby	?
28	12-2-2014	N 50 39.010 E 5 59.979	O	90	26	?	Yes	Yes, small concrete strip both sides	No	Yes, arrows	No	Cars, bikers, pedestrians, shops	Busy road, close to houses and shops, some trees nearby	Yes

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
29	12-2-2014	N 50 39.090 E 6 0.224	C	?	0,3	0,3	Yes	No	No	No	No	Pedestrians	Little water in it, close to water with picknick table, open grass, shrubs and trees, nearby houses	?
30	12-2-2014	N 50 38.873 E 5 59.447	C	?	?	?	Yes	No	No	No	No	Farmer	Not much water in it, fence in front of it, on slope with shrubs and trees, vegetation around it, open grass	?
31	12-2-2014	N 50 38.870 E 5 59.414	C	?	?	?	Yes	No	No	No	No	Farmer	Not much water in it, fence in front of it, on slope with shrubs and trees, vegetation around it, open grass	?
32	12-2-2014	N 50 38.859 E 5 59.349	C	?	?	?	Yes	No	No	No	No	Farmer	Not much water in it, fence in front of it, on slope with shrubs and trees, vegetation around it, open grass	?
33	12-2-2014	N 50 39.125 E 6 0.306	C	?	?	?	Yes	No	No	No	No	Farmer, pedestrians	No water in it, fence in front of it, on slope with shrubs and trees, nearby open grass, houses and water	?
34	12-2-2014	N 50 39.281 E 6 0.583	O	*69*	10,5	?	Yes	Yes, ±1m and ±2,5m concrete	No	No	No	Trains, pedestrians, cars?	Poorly maintained, partly for trains, sand on road, some shrubs and trees, nearby footpaths and open grass	Yes
35	12-2-2014	N 50 39.448 E 6 0.828	O	*66*	*7,8*	?	Yes	Yes, ±1,5m concrete both sides	No	No	No	Cars, bikers, pedestrians	Open grass, houses nearby, some shrubs and trees	Yes
36	25-2-2014	N 50 40.009 E 6 1.626	U	*27*	3	*3,6*	Yes	No	No	No	No	Pedestrians	With culverts, next to railway underpass, close to water, shrubs and trees	Yes
37	25-2-2014	N 50 39.973 E 6 1.561	C	?	0,35	0,35	Yes	No	No	No	No	Pedestrians	Little water in it, fence in front of it, open grass, some shrubs and trees	?
38	25-2-2014	N 50 39.856 E 6 1.405	C	?	0,28	0,28	Yes	No	No	No	No	Farmer	Little water in it, on slope with shrubs and trees, open grass and houses nearby	?
39	25-2-2014	N 50 39.806 E 6 1.339	C	?	0,28	0,28	Yes	No	No	No	No	Farmer	Little water in it, on slope with shrubs and trees, open grass and houses nearby	?
40	25-2-2014	N 50 39.780 E 1.281	C	?	1	1,35	Yes	No	No	No	No	Farmer	Water in it, small pipe in it, under on slope with shrubs and trees, leads to small pool	?
41	25-2-2014	N 50 39.757 E 6 1.266	C	?	0,4	0,4	Yes	No	No	No	No	Farmer	Little water in it, on slope with shrubs and trees, open grass and houses nearby, close to small pool	?

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
42	25-2-2014	N 50 39.706 E 6 1.203	C	?	0,31	0,31	Yes	No	No	No	No	Farmer	Little water in it, open grass with farm, high on slope with shrubs and trees	?
43	25-2-2014	N 50 39.672 E 6 1.157	C	?	0,3	0,3	Yes	No	No	No	No	Farmer	Full of water and garbage, on small slope, open grass with farm	?
44	26-2-2014	N 50 40.083 E 6 1.718	C	?	0,7	0,7	Yes	No	No	No	No	Farmer	Little water in it, open grass, high on slope with grass	?
45	26-2-2014	N 50 38.913 E 5 57.622	U	?	?	?	Yes, partly	No	Yes, grass, scrubs and trees	No	No	Train	Railway in the middle, stone stairs, many grass, shrubs and trees, houses nearby	Yes
46	27-2-2014	N 50 40.599 E 6 2.430	C	?	*0,27*	*0,16*	Yes	No	No	No	No	Farmer	Full of mud and leaves, no water, open grass with houses, on small slope with shrubs and trees	?
47	27-2-2014	N 50 40.553 E 6 2.366	C	?	0,27	0,16	Yes	No	No	No	No	Farmer	Full of mud and leaves, no water, open grass with houses, on small slope with shrubs and trees	?
48	4-3-2014	N 50 38.988 E 5 55.642	C	?	?	?	Yes	No	No	No	No	Pedestrians	In Grunhaut forest, full of leaves, no water, open grass with houses, next to footpath behind fence	?
49	4-3-2014	N 50 38.990 E 5 55.674	C	?	?	?	Yes	No	No	No	No	Pedestrians	In Grunhaut forest, full of leaves, no water, open grass with houses, next to footpath behind fence	?
50	4-3-2014	N 50 38.993 E 5 55.711	C	?	?	?	Yes	No	No	No	No	Pedestrians	In Grunhaut forest, full of leaves, no water, open grass with houses, next to footpath behind fence	?
51	4-3-2014	N 50 39.007 E 5 56.359	C	?	?	?	Yes	No	No	No	No	Pedestrians	In Grunhaut forest, full of leaves, no water, open grass with houses, next to footpath behind fence, open grass nearby	?
52	4-3-2014	N 50 39.007 E 5 56.326	C	?	?	?	Yes	No	No	No	No	Pedestrians	In Grunhaut forest, full of leaves, no water, open grass with houses, next to footpath behind fence, open grass nearby	?

Crossing structure#	Date	GPS coordinates	O / U / C	L (m)	W (m)	H(m)	Paved	Berm	Vege-tation	Road marking	Light-ing	Human disturbance	General description	Confirmed at the other side
53	4-3-2014	N 50 42.700 E 6 6.414	C	?	1,8	2	Yes	No	No	No	No	Farmer	Edge of Landwehring, water in it, open grass, vegetation around it	Yes
54	4-3-2014	N 50 42.683 E 6 6.367	C	?	0,3	0,2	Yes	No	No	No	No	Farmer	Sand and leaves in it, on slope with shrubs and trees, open grass	?
55	4-3-2014	N 50 42.723 E 6 6.456	C	?	0,3	0,3	Yes	No	No	No	No	Pedestrians	No water in it, in Landwehring, not directly next to footpath, on slope with shrubs and trees	?
56	5-3-2014	N 50 42.254 E 6 5.478	C	?	*4*	*1*	Yes	No	No	No	No	Farmer	Square, lots of water in it, open grass, shrubs and trees	?

9. Appendix 2 Recommendations

At the 17 km long highway section 56 crossing structures are located, consisting of 12 overpasses, 10 underpasses and 34 culverts (figure 1). Only one of these crossing structures is built for wildlife. All other structures are designed for cars or pedestrians to cross the highway or for drainage of rainwater. Nevertheless, some of the crossing structures are also used by multiple animal species. For example, foxes have used one culvert regularly (45 recorded events in four weeks). Furthermore, badgers have used two underpasses which are mainly used by pedestrians (13 recorded events in six weeks). At only 12 crossing structures cameras could be placed. It is very likely that other structures are also used by animals to cross the highway. Several adjustments can make crossing structures more suitable for wildlife crossing.

Suitable crossing structures

Several factors are important for a crossing structure to be suitable for wildlife crossing. First of all, animals should be able to reach the crossing structure. For example, an underpass that is situated in a crowded town without anything guiding towards the structure will probably not be found by many animals. Whereas a culvert which is located in a forest will be reached more easily. Secondly, low human disturbance is important. Large overpasses with high traffic are not very suitable. Small underpasses which are only used by pedestrians during the day are more suited. Furthermore, vegetation cover and shelter in the structure and in the surrounding environment are also important.

Which crossing structures are suitable in the study area? Most overpasses do not seem suitable, since traffic is high at many of these structures. Underpasses that are mainly used by pedestrians seem to be more suitable. Here human disturbance is lower, especially at night when most animals are active. Underpasses that are short appear most appropriate, because animals can see the end of the tunnel and are only vulnerable for a short moment. The most suitable underpasses in the study area, their positive and negative characteristics and possible adjustments are depicted in figure 2 and table 1. Furthermore, culverts can be very suitable too. Especially when they are located in a forest and do not contain (much) water. However, for most culverts it was unclear whether they end up at the other side of the highway. Perhaps, some of the culverts are part of a larger drainage network. Animals that enter a culvert could cross the highway or may end up somewhere else.

Adjustments

Possible adjustments to increase the use of crossing structures in the study area by animals such as wildcat are depicted in table 2. Overpasses do not seem very suitable. Therefore, the focus should be on improving underpasses and culverts (figure 2). The following culverts have a width or diameter of one meter or larger in which shelves can be placed: 12, 13, 40, 53 and 56. The width of culvert 8 is unknown, but is seems possible to place a shelf in it. In addition, fences to prevent animals entering the highway and rasters to guide animals to the crossing structures can decrease mortality rates significantly.

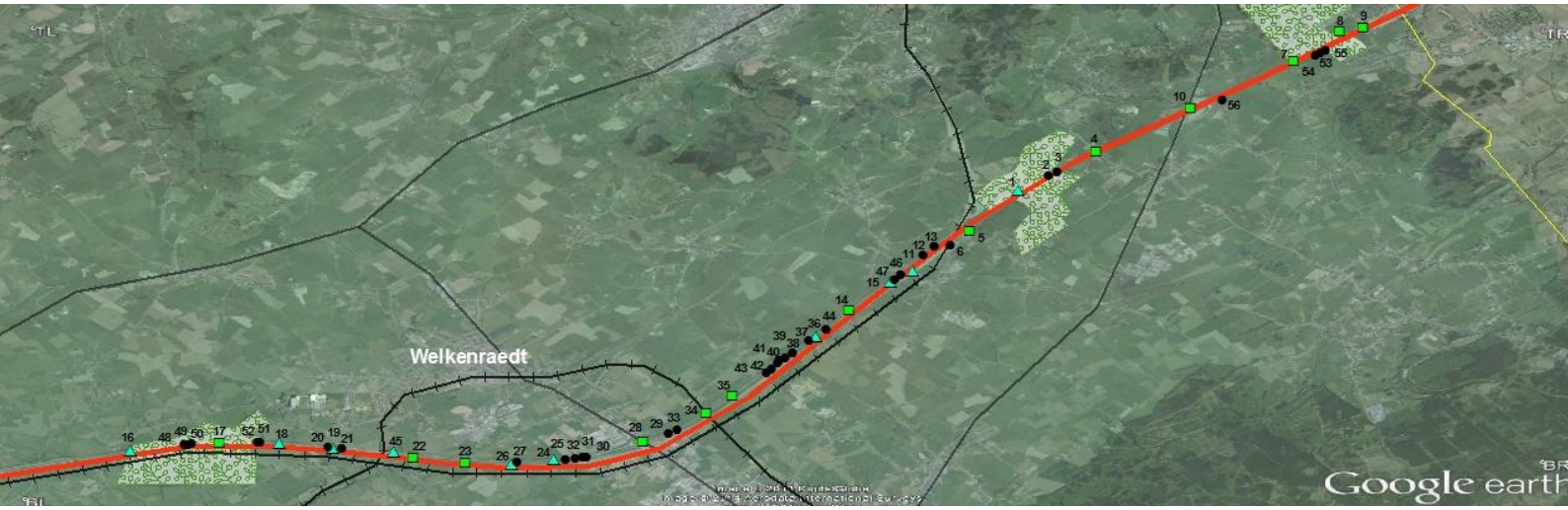

Figure 1. Overview of all crossing structures. Green squares are overpasses, blue triangles underpasses and black circles culverts. The red line is the highway E40 and black lines are smaller roads nearby. Black lines with stripes are railways and the yellow lines represents the border with Germany. Three forests are situated in the study area, depicted in white with green leafs (from west to east: Grunhaut forest, Buchenbusch and Landwehring).

Figure 2. Overview of possible adjustments for suitable underpasses and culverts. Green triangles are underpasses where vegetation and shelter can be provided. Brown circles are culverts where shelves can be placed. The red line is the highway E40 and black lines are smaller roads nearby. Black lines with stripes are railways and the yellow lines represents the border with Germany. Three forests are situated in the study area, depicted in white with green leafs (from west to east: Grunhaut forest, Buchenbusch and Landwehring).

Table 1. Positive and negative characteristics and possible adjustments of the most suitable underpasses in the study area.

Crossing structure	Positive	Negative	Possible adjustments
1	In forest, mainly pedestrians	Quite long, no vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
15	Mainly pedestrians, short	Not in forest, no vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
16	In forest, mainly pedestrians	Long, no vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
18	At forest edge, mainly pedestrians, short	No vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
26	Mainly pedestrians, short	Not in forest, no vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
36	Mainly pedestrians, short	Not in forest, no vegetation or shelter in tunnel	Provide shelter and vegetation in tunnel
45	Wide and open, vegetation and shelters present	Railway track, close to some houses	

Table 2. Possible adjustments for culverts and underpasses in the study area.

Culverts	Underpasses
Check culverts regularly for blockages, for example caused by mud	Provide shelter in and around underpasses that are mainly used by pedestrians
Place shelves in (large) culverts which contain water	Provide vegetation in and around underpasses that are mainly used by pedestrians
Provide vegetation around entrances of culverts	

10. Appendix 3 Photos of crossing structures


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