Animals “got to go”

A conceptual proposal for developing wildlife corridors and enhancing the Älby overpass in Nynäshamn Municipality, Sweden

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Swedish University of Agricultural Sciences, SLU
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Abstract

Nynäshamn municipality, located in Stockholm County, is connected to the capital via National Road 73, which constitutes a barrier to wildlife. A mitigation measure in the form of an overpass was constructed to enhance the lost habitat connectivity. However, the municipality's growth plans include significant expansion of the urban sprawl by 2040, which will threaten wildlife by fragmenting habitats and increasing disturbance near the overpass. This thesis investigates the impact of urbanization on local wildlife and assesses the efficacy of the overpass, aiming to restore wildlife connectivity with green corridors and proposed design improvements to the overpass.

Analysis revealed time-separation in human and wildlife usage of the overpass, suggesting that co-usage is feasible without significant impacts on wildlife. Moreover, the thesis studies the habitat requirements of moose with the aim of improving the overpass efficacy and habitat connectivity. The Wildlife Habitat Relationship (WHR) method identified moose's habitats and highlighted the scope of their fragmentation, also emphasising overpass to be the only sufficient habitat connection in the area. Consequently, a proposal for a revised overpass was developed together with a design for habitat connectivity in the form of green corridors.

Proposed overpass improvements include removing dense vegetation at the entrance, replacing it with ground cover species preferred by moose, extending acoustic screens to reduce light and noise disturbances, and adding natural features like rock and branch piles inspired by the Sandsjöbacka ecoduct. Moose habitats were conceptualized based on life requisites, including feeding, cover, and reproductive areas, highlighting the importance of lakes, ponds, wetlands, and various vegetation types for habitat connectivity.

Despite the complexity of urbanization impacts this thesis recommends protecting habitat connections by limiting urban sprawl and establishing land protection measures. In conclusion, the thesis presents design recommendations to develop wildlife corridors and improve overpass efficiency, aiming to enhance wildlife populations in Nynäshamn while promoting coexistence and ecological sustainability.

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Contents

Introduction

Nynäshamn is a small town with a population of around 15,000 inhabitants south of Stockholm, in which county it lies. The municipality, also named Nynäshamn, is the southernmost in the county. National Road 73 connects Nynäshamn to Stockholm, creating a barrier for both wildlife, especially ungulates, and people (Håkansson et al. 2022). Mitigation measures have been developed and applied to reduce the negative effects of the infrastructure, such as a wildlife crossing structure (WCS) in the form of an Älby overpass. It spans over Road 73 allowing safe wildlife passage and connecting important habitats, thereby enlarging wildlife's territories that otherwise would remain isolated.

The municipality's vision is focused on growth and development (Nynäshamn Municipality 2024b). Plans indicate that 55 per cent of growth before 2040 will occur as urban sprawl, further fragmenting, and consuming wildlife habitats. Moreover, a substantial part of urbanization spreads in close vicinity to the overpass, not only limiting wildlife's territory but also creating disturbance. Consequently, the mobility and therefore survival of the wildlife population are in danger (Smith et al. 2015). The overpass is at risk of failing due to new developments fragmenting nearby habitats and increasing the likelihood of wildlife mortality from more car traffic. Development, which takes place at the expanse of nature, does not align with sustainability principles (Telsaç and Kandeğer 2022). Sustainable developments avoid the degradation and destruction of local habitats and in cases where no more avoidance is possible, mitigation measures are introduced (Telsaç and Kandeğer 2022, Smith et al. 2015).

This thesis investigates the developments threatening local wildlife populations and the efficacy of the overpass in accommodating wildlife. Additionally, it aims to identify wildlife movement corridors and develop design strategies to improve the structure's efficiency. Through comprehensive analysis and design alterations, this thesis proposes movement corridors, utilizing the overpass to ensure connectivity from east to west. An attempt to lessen the extent of human development pressures on wildlife is being made enhancing the structure’s functionality and improving habitat connectivity.

1.1 Background

The study site (Fig. 1), an overpass designated for wildlife mobility, is located in Nynäshamn municipality, Sweden. The structure spans over National Road 73 (Riksväg 73) which connects Stockholm and Nynäshamn. Due to the barrier effect created by Road 73, wildlife crossings are a major way animals move between habitats.

Figure 1 Site location map (map source: Lantmäteriet, modified by author)

Thus, the report commissioned by the Swedish Transport Administration identifies and prioritizes road sections that need mitigation measures to reduce barrier effects and limit wildlife accidents in Stockholm County (Håkansson et al. 2022). The research concluded that Road 73, when analysed with its surroundings, has an immense barrier effect and the priority for mitigation action is high (Fig. 2, Håkansson et al. 2022). It is important to mention that in their perspective as a traffic authority, sections with the highest traffic accident rates were prioritized for safety. The report categorizes roads, including those with fences or allowing speeds exceeding 100 km/h, as barriers, among other classifications and was based on the theoretical mobility efficiency of moose, which was used as a model species (Håkansson et al. 2022). Road 73 checks both of those categories thus it is constituting a strong barrier to wildlife. Therefore, east-west connectivity needs to be enhanced to improve wildlife sustenance, particularly for moose (Fig. 3 and 4).

Figure 2 Selected road and railway segments in need of wildlife mitigation action (map source: Lantmäteriet, modified with input from Håkansson et al. 2022)

As infrastructure and urbanization pressures increase, particularly due to urban sprawl, the barrier effect and habitat loss threaten local wildlife populations, leading to significant biodiversity loss (Forman & Alexander 1998; Torres et al. 2016). Urbanization often creates more severe barriers than agricultural land use (Rezvani et al. 2024), driving wildlife to move more frequently in search of resources, which heightens the risk of wildlife-vehicle collisions (Borowik et al. 2020). The habitats surrounding the wildlife Älby overpass face the threat of disappearing without protective measures. The area's growing population, particularly the planned addition of up to 3,000 new residents in Källberga (yellow & orange circles Fig. 3), threatens local wildlife by encroaching on arable land, forests, and meadows. This expansion underscores the urgent need to address habitat loss and fragmentation through both avoidance and mitigation strategies (Smith et al. 2015).

In light of these challenges, the sustainability of urban development and landscape management, particularly in protecting wildlife habitats, was a key factor in site selection. The impacts of the Källberga development on local wildlife were analysed, with a critical focus on wildlife connectivity, particularly the reliance on the overpass that links habitats from east to west. The thesis also addressed the broader issues of urbanization and its effects on wildlife, offering a comprehensive assessment of the challenges posed by the development.

Human disturbance and developments

The area surrounding the overpass was analysed, leading to the development of an interpretation and a map to understand current and future disturbances caused by human activities. This analysis also assessed whether these disturbances might hinder the effectiveness of the crossing.

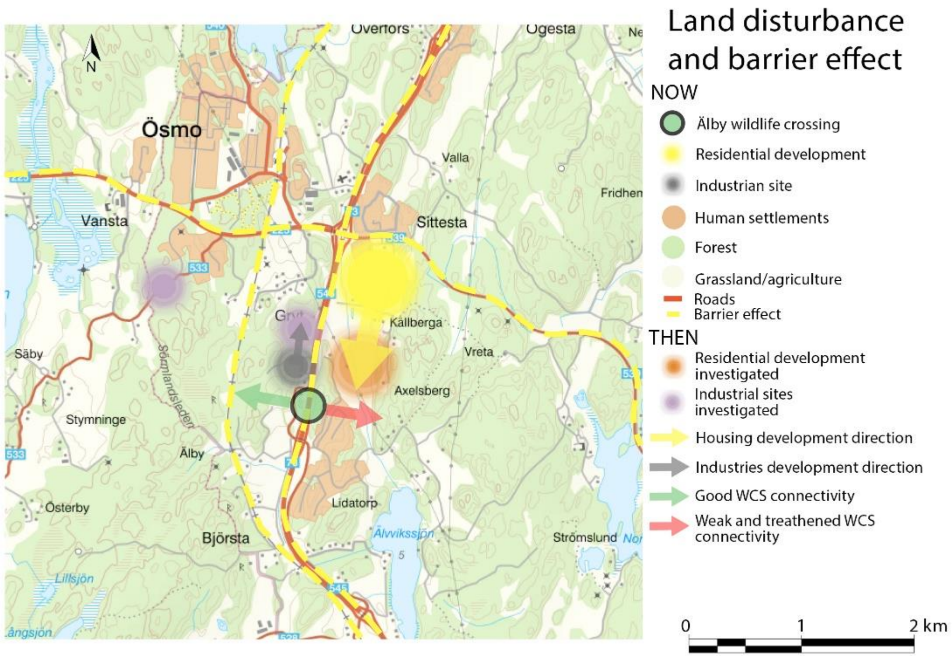


Figure 3 Land disturbance and barrier effect (map source: Lantmäteriet, modified with input from Nynäshamn municipality 2024c, Håkansson et al. 2022)

Running north to south, as indicated in yellow (Fig. 3), the railway (on the left) and National Road 73 (on the right), which connects Stockholm with Nynäshamn, create a significant barrier effect, further fragmenting habitats. The railway route is identified as a high priority for action concerning barrier effects and traffic safety (Fig. 2, Håkansson et al. 2022). Expanding the municipal green infrastructure to encompass the area surrounding the overpass is crucial for establishing vital wildlife corridors. This expansion would significantly enhance the overpass's effectiveness, enabling broader landscape connectivity and allowing for more seamless movement of species across the region. The former road, in particular, has notably high mortality rates. Fig. 20 illustrates the moose mortality associated with these roads. Industrial sites are not expected to pose a significant risk of excessive anthropogenic disturbance to moose and are unlikely to directly impact the overpass due to expanding away from the overpass and being situated near existing roads, they will not create new barriers for wildlife movement. The western entrance to the overpass is and will remain penetrable for wildlife, although the eastern entrance will be affected by urbanization. New developments in Källberga might isolate the overpass from nearby habitats, particularly the Ällvviksjön lake southeast of the crossing, by creating an urbanized area around the overpass (Fig. 3). Therefore, these challenges could be addressed through the implementation of movement corridors, which are essential for preserving habitat connectivity.

Municipal green structure

The analysis of the municipal green structure plan (Fig. 4) highlights north-to-south connectivity and reveals insufficient connection from west to east, where intervention is most needed, as indicated with arrows (Fig. 4).

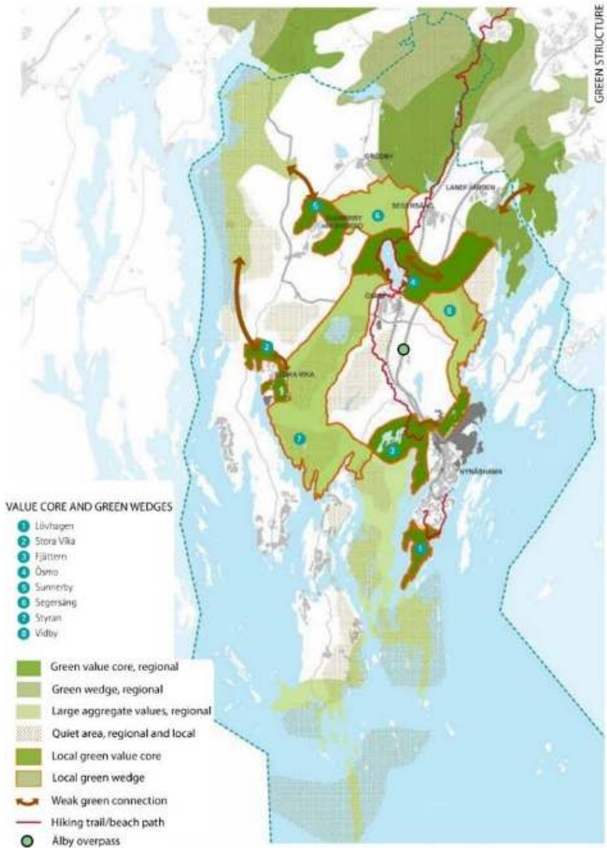


Figure 4 Green structure map for Nynäshamn municipality (map source: Nynäshamn municipality 2024c, modified by author)

The overpass is not integrated into the broader green structure plan, missing an opportunity to address the significant barrier effect posed by the railway and National Road 73. The green structure map overlooks critical infrastructure that contributes to habitat fragmentation and barrier effects. This thesis proposes enhancing habitat connectivity, focusing on high-mobility species like ungulates, to improve wildlife sustenance. Moreover, expanding the municipal green infrastructure to include the area surrounding the overpass is crucial for establishing vital wildlife connectivity on a regional scale and fully unlocking the overpass's potential by enhancing landscape connectivity.

Species selection

Moose (Alces alces alces) have been selected as the umbrella species for this study due to their ecological importance and the specific challenges they face. Data shows that moose are disproportionately affected by vehicle collisions, with their roadkill percentage increasing from 8% in 2022 to 10% in 2023, despite representing only 1% of wildlife crossing users between 2019 and 2020 (on page 52). This indicates a high vulnerability and underscores the need for species-targeted conservation efforts. Addressing the needs of moose not only supports this species but also benefits other ungulates, promoting broader ecological connectivity and resilience. Additionally, climate change further threatens moose populations, particularly in southern regions, making their protection critical.

2. Aim and research questions

This thesis aims to implement protective measures to enhance habitat connectivity and improve wildlife conservation in Nynäshamn municipality, with a particular focus on addressing urbanization and developments that threaten local fauna. Specifically, the thesis centres on the development of wildlife corridors and a detailed design proposal for an enhanced Älby overpass on National Road 73. The goal is to increase wildlife mobility in the landscape by incorporating the overpass into the corridors and improving its efficiency. Thus, the design proposal will better accommodate the needs of wildlife affected by urbanization in Nynäshamn.

The proposed corridors will improve habitat connectivity and facilitate wildlife movement. The study seeks to develop a more effective and wildlife-friendly crossing by evaluating the current overpass to determine if it adequately supports wildlife mobility and identifying design changes that could improve it. Both objectives are based on a case study of moose (Alces alces), used as an umbrella species. The design proposal may include modifications to the existing structure, the creation of a new crossing, or restrictions on human use if necessary.

The research question, no. I address the wildlife sustenance in nearby landscapes. Question no. II proceeds from it, by incorporating a detailed focus, addressing the effectiveness of the overpass. Both considerations are important because wildlife are primary users of the overpass, and without whom the crossing cannot fulfil its function.

Research question: I: How can moose habitats and populations be protected from urbanization and infrastructure developments in Nynäshamn municipality, particularly in relation to the Älby overpass?

Question no. I attempt to examine the species' sustenance in the nearby area of the crossing. The investigation is based on an analysis of nearby landscapes, which attempts to explore species' habitats and their connectivity.

Research question II: How can design elements and solutions be strategically employed to maximize the efficiency of an overpass, while ensuring the successful integration of human and wildlife usage, using moose as an umbrella species?

Question no. II aims to examine potential enhancements that could be done to the overpass to further its efficiency and address wildlife populations' needs. It also focuses on integrating wildlife and human usage of the crossing which has to be achieved without impacting wildlife sustenance negatively. Lastly, it uses moose as an umbrella species, meaning the requirements are based on this particular species.

3. Methodology

This research is based on the philosophy of pragmatism, which emphasizes practical solutions to real-world problems through an iterative process, which uses initial results to develop a more comprehensive solution (Morgan 2007). The research method combines qualitative and quantitative approaches, reflecting pragmatism's value on diverse data to inform practical and adaptable solutions.

3.1 Literature review

The literature review covers various topics, including wildlife crossing structures (WCS), their effectiveness in accommodating targeted species, and relevant design principles. Consequently, this study focuses on moose as an umbrella species, examining its habitat requirements. Additionally, literature on the integration of human and wildlife usage of WCS and its maintenance was researched. Insights from this review informed the criteria for the design proposal of the revised overpass. The role of landscape architecture was conceptualized using the Wildlife Habitat Relationship (WHR) method. Research on sustainable urbanization and urban sprawl was also conducted to create a framework for analysing urbanization in Nynäshamn and developing protection measures. Important findings within the literature and data regarding the selected crossing were acquired from the TRIEKOL project, a collaborative effort between SLU and the Swedish Transport Administration focused on applied road and rail ecology (Triekol n.d.a). Consequently, a framework was developed based on the literature review, leading to the formation of an analysis method and design.

3.2 Species selection

This study focuses on the group of ungulates due to their significant role in biological diversity and their importance from ecological, economic, and educational perspectives (Reimoser & Nopp-Mayr 2024). This group of animals is usually larger than other species, requires substantial land areas, and exhibits higher rates of mobility (Rezvani et al. 2024). Therefore, they are highly impacted by habitat fragmentation and barrier effects caused by infrastructure (Rezvani et al. 2024). Additionally, there are many car and railway collisions with ungulates, which present high economic costs for society and negatively affect wildlife populations (Dorsey et al. 2015).

While wildlife crossings are typically designed for specific species, they are also expected to accommodate a diverse range of animals. To navigate the tension between specificity and generality, larger crossings designed to accommodate larger mammals often consider an umbrella species, such as moose (*Alces alces*), which is selected for its high requirements (Seiler et al., 2015). It is partially because moose are solitary living species and their behaviour is not easily learned, making adaptation more difficult (Lodnert 2021). The design should adhere to the needs of the umbrella species while trying to integrate additional features that support other wider variety of animals, provided these enhancements do not impede the habitat utilization of the primary species.

Moreover, North American moose are expanding their habitat north, while southern populations are faced with declines due to changing climate and one of the hypotheses is that they are unable to deal with excessive heat due to weak thermoregulatory abilities (Murray et al. 2006, Lenarz et al. 2009 see Holmes 2021). A similar fate is hypothesized to touch European moose populations (Dou et al. 2013, Malmsten 2014 see Holmes 2021). Moreover, climate change effects and impacts are exacerbated by the degradation of species' habitats. This combination poses a significant threat to the moose population. Therefore, the European moose (*Alces alces alces*), was chosen as an umbrella species.

3.3 Case study method

The case study method is compatible with the philosophy of pragmatism and was used to develop design proposals for wildlife corridors and an enhanced overpass. This qualitative research approach explores phenomena within their real-life contexts, typically bounded by time and activity (Priya 2021). Additionally, analysing phenomena in their natural settings is crucial, as it provides insights into the effectiveness of overpasses based on wildlife behaviour and environmental factors. The emphasis on methodology ensures that research questions are addressed with clarity and precision, providing clear guidance. The holistic approach results in theoretically sound and practically viable designs, connected to real-world scenarios (Priya 2021). Guidance for design improvements was derived from a literature review which was anchored in the research questions, aiming to address and answer them comprehensively. Additionally, a comprehensive site analysis was conducted with the aim of understanding the geographical context, human-wildlife dynamics, wildlife habitats and the overpass.

3.4 WHR analysis

Habitats required for the moose sustenance were analysed based on WHR methodology. The Wildlife Habitat Relationship (WHR) method evaluates landscapes and habitats by dividing them into functional units: feeding habitat, cover habitat, and reproductive habitat (Cooperrider, 1986; see Greco n.d.). These units are analysed to conclude species sustenance. Moreover, habitats tend to be represented on a map in the form of land cover using colours to represent the systematic classification of vegetation communities (Greco n.d.). Therefore, mapping was created with ArcGIS and Photoshop. Consequently, habitats were divided into categories based on targeted species requirements. Such classification helps to determine suitable environments for the species. The WHR maps are based on National Land Cover Data which is a comprehensive mapping of Sweden and was gathered from The Swedish Environmental Protection Agency (2023). The map was released in 2020 and consists of a base mapping in 25 thematic classes at three hierarchical levels. The mapping is in a raster format with a resolution of 10 meters and a minimum mapping unit down to 0.01 hectare. Habitat types are a conjunction of the primary categories of the source map and the methodology is showcased below.

In the WHR analysis, the overpass was also considered but at a smaller scale using a different method. Given that the map provides accuracy to within 10 meters, applying the same process as in other areas was not feasible. Instead, a new method was employed, focusing more on site-specific analysis and assessing the presence of moose habitats. These assessments, based on the criteria discussed in the chapter titled Moose, are inherently subjective and reflect the opinions formed during the site visit. Additionally, the WHR considerations and analysis of the overpass are less structured and not as straightforward as the WHR analysis.

WHR classification	Feeding habitat (summer)	Feeding habitat (winter)	Cover habitat	Reproductive habitat	Arable land	Open land without vegetation	Exploited land	Transport infrastructure
Input data	Lakes and waterways	Pine forest (outside wetland)	Coniferous mixed forest (outside wetland)	Open wetland	Arable land	Other open land without vegetation	Exploited land, building	Exploited land, road/railway
Input data	Mixed deciduous coniferous forest (outside wetland)	Temporarily not forested (outside wetland)	Spruce forest (outside wetland)	Other open land with vegetation			Exploited land, not building or road/railway	
Input data	Decidous forest with decidouos elements (outside wetland)	Pine forest (on wetland)	Spruce forest (on wetland)					
Input data	Decidous forest (on wetland)	Coniferous mixed forest (on wetlands)						
Input data	Broadleaf forest (on wetland)	Mixed decidous coniferous forest (on wetland)						
Input data	Decidous forest with decidous elements (on wetland)							
Input data	Temporarily not forested (on wetland)							

Table 1 Land cover data converted into WHR model

Feeding habitat	Cover habitat	Reproductive habitat	Other
summer	coniferous forest	open landscapes	arable land
lakes and wetlands			open land
seral forest (temporary not forested)			exploited land
forest			transport infrastructure
winter			
forest			

Table 2 WHR analysis model

Feeding habitat	Cover habitat	Reproductive habitat	Other
lakes and wetlands	coniferous forest	open landscapes	arable land
forest			open land
			exploited land
			transport infrastructure

Table 3 WHR analysis model simplified

3.5 Site analysis

A case study is conducted via a site analysis of the area of interest, specified further in the text. As part of the site analysis, some quantitative data was used, which includes wildlife mortality data gathered from the National Wildlife Accident Council (n.d.). The Council gathers input information from national data on wildlife mortality and accidents conducted by the Swedish police. Data was acquired on 29th February for the following years; 2022, 2023, 2024. Because it takes time to process the data, the information is probably from two months before the access date. The data set covers the whole Nynäshamn municipality. Moreover, a moose wildlife accidents map was acquired from the Swedish Transport Administration for the 5 years, between 2018 and 2022. Wildlife usage of the overpass statistics were acquired from Triekol (n.d.a) and include entry data from 19th April 2019 for human crossings and 26th July 2019 for animals. The last recorded entries were from 4th August 2020 for both categories. Mortality and overpass usage data were used to conclude which species are affected by barrier effect the most and if the WCS is being sufficiently used by umbrella species. It also guides the feasibility of integrating human and wildlife usage.

The assessment areas are based on the typical moose home range, which equals 10-60 km2 (Beest et al. 2011; Cederlund & Sand 1994; Murray et al. 2012 see Janík et al. 2021). Consequently, WHR analysis was conducted within the maximum home range which equals 60 km2. The site visit included a land area of 10 km2 and was conducted on 23rd March 2024.

4. Literature review

4.1 Biodiversity loss due to habitat fragmentation

Humans are the main factor of current biodiversity loss on Earth (IPBES 2019). The natural world has been impacted by multiple human drivers in a major way and most of the ecosystem and biodiversity indicators are showing a dramatic decline (IPBES 2019). Around 75 per cent of the land surface on Earth is altered in a significant way and more than 85 per cent of the wetland area was lost (IPBES 2019). In human history, the change in nature has never been as rapid as in the last 50 years (IPBES 2019).

> "Agricultural expansion is the most widespread form of land-use change (…). This expansion, alongside a doubling of urban area since 1992 and an unprecedented expansion of infrastructure linked to growing population and consumption, has come mostly at the expense of forests (...) wetlands and grassland." (IPBES 2019:18)

Moreover, worldwide paved roads are predicted to reach a length of 25 million kilometres by 2050 (IPBES 2019). This expansion, together with the development of cities, might cause extensive environmental and social costs, which include among others habitat fragmentation, biodiversity loss, community displacement, and social disarrangement (IPBES 2019). Therefore, a major factor in habitat fragmentation and biodiversity loss on Earth is transport infrastructure, which is increasing year by year (Ree et al. 2011). Many species decide to cross the roads and transport infrastructure, sometimes risking their lives, in Sweden, in 2023 alone there were 68,697 registered vehicle collisions with larger wildlife (National Wildlife Accident Council n.d.). As a result, wildlife subpopulations are vulnerable to local extinctions, which threaten their long-term viability and lead to a decrease in biodiversity (Rytwinski and Fahrig, 2015; Bennett, 2017 see Denneboom et al. 2021).

There are many consequences of natural environment fragmentation, some of which are direct, while others are indirect, and their evaluation is complex (Corlatti et al. 2008). A theory within the field of conservation biology suggests that the construction of wildlife corridors that connect isolated habitat patches might benefit, or at least maintain gene flow and ensure the population viability of targeted species (Corlatti et al. 2008). Therefore, crossing structures for wildlife are being incorporated into newly constructed roads and improvement projects of existing infrastructure (Corlatti et al. 2008). Moreover, they allow safe animal movement across the road, contributing to animal and human safety (Corlatti et al. 2008). Consequently, a lot of effort has been invested into mitigation and it is becoming increasingly common to build wildlife crossing structures (Ree et al. 2011).

4.2 Examples of wildlife crossing structures used by moose

The main category of distinction of WCS is overpasses, which are built as bridges above roads and railways, and underpasses which are more common and are built as a tunnel below the infrastructure to allow wildlife movement (Smith et al. 2015). The structures are classified further into many different types, mostly being differentiated by the size of the designated species to use the structure, in this case, moose (Denneboom et al. 2021). Overpasses categories include ecoducts that frequently reach more than 50 metres in width and lean towards restoring landscape and habitat connection, also known as green bridges (Smith et al. 2015). Accordingly, to Swedish Transport Administration does not focus on specific animal species but rather on many different types of animals (Swedish Transport Administration 2020).

Figure 5 Example of an ecoduct, Singapur (Benjamin P. Y-H. Lee, University of Kent)

Wildlife overpasses tend to be narrower, estimated at around 20 m (Smith et al. 2015). The width of the overpass might affect the rates of various habitat types expressed in vegetation strips, soil type, or vegetation cover (Smith et al. 2015). A limited amount of those habitat zones could result in a smaller variety of species that use the structure (Smith et al. 2015). Overall, overpasses offer a great diversity of species that can use the structure, including ungulates, large herbivores, and invertebrates (Smith et al. 2015). A generalization that higher and wider structures are utilized by larger animals, a higher number of different species, and finally with higher rates of target populations, could be made (Rosell et al. 2023).

Figure 6 Älby overpass

There are two main types of underpasses used by moose. The biggest are viaducts and long or open-span bridges which are often passing over valleys (Smith et al. 2015). Significantly, viaducts are the most effective WCS for large mammals compared to overpasses and underpasses (Denneboom et. al 2021).

Figure 7 Example of a viaduct (MBugbey)

Typically, smaller wildlife crossings are underpasses which vary in size and type (Smith et al. 2015).

Figure 8 Example of an underpass targeting bears (U.S. Dept. of Transportation)

4.3 Feasibility of integrating human and wildlife usage of the overpass and their movement needs

WCSs are primarily constructed to facilitate the movement of wildlife, although some of them allow co-use by humans, often for recreation. Such structures may be used by both wildlife and humans, for example, farmers (Corlatti et al. 2008). However, it is widely accepted that human activity leads to ungulates stress that results in excessive alertness and being watchful due to the perceived risk of predation and other hazards to their safety (Pecorella et al. 2016). Such behaviour is observed within transportation infrastructure and mitigation structures and can affect crossing rates by ungulates (Knufinke et al. 2019). Growing demand for humans to use wildlife crossings resulted in a growing body of literature within the field, however, it is in its early stages of scientific consensus on how to design a successful co-use structure. It might be the case that the collaborative use of humans and animals is having unacceptable impacts on the wildlife population, which would lead to prohibiting people from using the structure and building another crossing nearby (Ree and Grift 2015).

In the study conducted by TRIEKOL, a temporal pattern regarding wildlife and human usage was researched (Knufinke et al. 2019). The studied species were within an ungulate family, for which the structures were designed (Knufinke et al. 2019). Two of the species studied, moose (*Alces alces*) and roe deer (*Capreolus capreolus*), are prevalent in Nynäshamn municipality and suffer notable casualties due to vehicle collisions on roads (National Wildlife Accident Council n.d.). The study defines disturbance as:

> "ungulates reaction on human usage of the structure that leads to an alteration of their usage pattern or to avoidance of the crossing structure." (Knufinke et al. 2019:2).

Results show that 90% of human activity takes place between 9 am and 9 pm and was congruous at all crossings researched (Knufinke et al. 2019). Overpasses experienced a peak in visits by people during midday (Knufinke et al. 2019). Moose used crossings primarily at dusk and at night, with the highest activity at 5 PM and species usage was lower within days of higher human activity (Knufinke et al. 2019). Additionally, there was a significant difference in usage regarding the timespan between crossing events. Moose used the overpass within a significantly shorter time if the prior crossing was made by another moose rather than a human which indicates avoidance behaviour (Knufinke et al. 2019). Such findings were made in multiple publications and portray low ungulate presence within high human activity periods (Knufinke et al. 2019). However, the research is inconclusive regarding the theory that ungulates avoidance behaviour lowers the overall rates of use. It is suggested that because of the temporal delay in wildlife usage after human use, animal usage rates might be impacted in a negative way (Knufinke et al. 2019). Research shows that wildlife portrays a very distinctive separation in time from humans (Knufinke et al. 2019), meaning that separation in space might be obsolete if the animals are not comfortable being in the vicinity of the crossing in times of high human activity. This suggests that wildlife crossing structures with clearly defined time separation between wildlife and people are likely not adversely impacted by human activity (Knufinke et al. 2019).

Some research suggests that crossing structures aimed to accommodate endangered species or those with a high-priority profile should increase their width (Ree and Grift 2015). Such a suggestion is made for structures with time separation not clearly defined. Moreover, such recommendations lack empirical data to prove them and are mainly based on theories. Consequently, some ongoing studies suggest that animals choose to walk along human-made paths on crossings. In most cases, additional costs to the structure should be empirically proven.

Finally, many recommendations advocate that co-use by humans of wildlife passages should be discouraged. On the other hand, more research needs to emerge to support that theory, and the research that is available now, suggests that this phenomenon of wildlife avoiding humans in and around WCS is species-specific (Ree and Grift 2015). Multiple studies could not link human activity with any changes within wildlife patterns and the wildlife rate of crossing on passages. Probably human use is possible when restricted to times and hours when wildlife is less active and the rates of use by people are low (Ree and Grift 2015, Knufinke et al. 2019).

4.4 What makes WCS successful?

Many studies focused on the impact of structure dimensions such as span, width, height, and quality of openness. Therefore, overpasses with prolonged lengths and vegetation cover within the entrance were found to impact ungulates rates of use negatively (Nget al., 2004; Clevenger and Waltho, 2005; Wang et al., 2018 see Denneboom et. al 2021). The research is inconclusive regarding structure width. For example, the overpasses' width had a negative correlation to the ungulates proportion of successful crossings of the structure, on the other hand, it had a positive impact on large carnivores (Craveiro et al., 2019; Serronha et al., 2013; Grilo et al., 2008; Mata et al., 2003 see Denneboom et. al 2021). It means that wider structures might limit the use of ungulates and one of the possible explanations is that the presence of carnivores creates fear of predation within ungulates creating avoidance of those structures (Denneboom et. al 2021). Some of the structural qualities have yet to be broadly studied, including shape, substrate, and construction materials, and some studies suggest that those attributes can influence usage patterns (Denneboom et. al 2021). Regarding materials that animals encounter, it is important to note that natural materials in comparison to concrete had a significant impact on the proportion of successful crossings (Patrick et al. 2010 see Denneboom et. al 2021). Consequently, moisture retention is critical for a healthy ecosystem and can be achieved by choosing fitting soils, vegetation, leaf debris, and other types of ground surface (Smith et al. 2015).

Another structural characteristic affecting wildlife is the fencing. Fences applied to roads and railways are considered one of the key road mitigation measures, they forbid animals from accessing the lanes and indicate to promote the ungulate use of underpasses, by directing the movement toward the structure (Denneboom et. al 2021). In other words, fencing is suggested to be required to channel wildlife towards the WCS. Design elements and material of fences are important considerations and may provide multiple benefits, such as noise reduction, anthropogenic light reduction, and limited pollution which would otherwise lead to restraint by some species (Smith et al. 2015). Such screening proves to be a successful mitigation measure, and its detailed design depends on targeted species, anthropogenic impacts to be mitigated, aesthetics, and local conditions (Smith et al. 2015, Ree and Grift 2015). Moreover, the Swedish Transport Administration's regulatory document "The Ecological and Cultural Heritage Standards" calls for the elimination of noise disturbance (Trafikverket 2015). Such anthropogenic stimuli are believed to scare wildlife and lower the rates of use (Smith et al. 2015). It is important to note that fencing negatively impacts large carnivores' use of overpasses, which may, in turn, increase the usage rates by ungulates that might otherwise avoid WCS due to the risk of predation (Denneboom et. al 2021).

The location and spacing of crossing structures greatly influence the wildlife rates of usage (Smith et al. 2015). Both factors, among others, should be based on ecological and biological variations (Smith et al. 2015). Therefore, such structures need to be located in areas with maximum interest in targeted species, possibly within movement pathways. On the other hand, quite often movement patterns are unknown to researchers and planners, and some locations are characterized by dispersed mobility configurations (Smith et al. 2015). In such cases, crossings can be placed along riparian corridors, which are plant communities along water bodies (Smith et al. 2015). Other placement proposals include green corridor intersections with roads characterised by resources located on the other side of the road (Smith et al. 2015). It might be the case that the construction of several small crossings is more beneficial to wildlife than one single large crossing due to the habitats and landscape changes, which occur over time, and when human development is out of control (Helldin 2022).

Additionally, the mitigation goal is partially dependent on the wildlife movement patterns (Smith et al. 2015). It can be characterized as a daily occurrence, such as food access, occasional which includes maintenance of gene flow, and seasonal for example in the case of winter migration (Smith et al. 2015). Therefore, based on that, the number and spacing of WCS is decided. Furthermore, the biological and ecological needs and requirements of targeted species will determine the design, size, and type of structure (Smith et al. 2015). For example, in Zachodniopomorskie voivodeship in Poland, young moose did not want to use the underpass and tried to jump over the fences to cross the highway. Even after being directed by people to cross the road by going through the designated structure, they were too uncomfortable to do so, because of too small dimensions of the structure for this particular species (Korytarze ekologiczne 2021). Therefore, both animal species and people need to not only fit within the structure itself but also feel behaviourally comfortable with its dimensions, substrate type, and surroundings (Smith et al. 2015).

Such behavioural patterns might be influenced by many ungulates being prey species, meaning that their natural environment is inhabited by predators, and they have developed adaptations to be wary of predation (Denneboom et. al 2021). Enclosed spaces exaggerate this effect, making them unsuitable for those species, where they perceive an extra risk of predation (Clevenger and Waltho, 2005 see Denneboom et. al 2021). Moreover, ungulates prefer clear sight to be wary of any potential predators (Smith et al. 2015). It might explain why overpasses, especially without dense vegetation at the entrances, are generally preferred by ungulates (Clevenger and Waltho 2005 see Denneboom et. al 2021). The usage of WCS is reduced when structural characteristics and surroundings are perceived as unsafe by wildlife (Denneboom et. al 2021, Smith et al. 2015, Knufinke et al. 2019). Moreover, human disturbance could be perceived as a threat by some individuals (Knufinke et al. 2019).

4.5 Wildlife crossings in Sweden

Many wildlife crossing structures targeting larger species have been constructed or are being built in Sweden (Triekol n.d.b). These structures vary greatly in dimensions, vegetation representation, technical solutions, and cost-effectiveness, adding complexity to the topic (Triekol n.d.b). Wildlife crossings in Sweden began being constructed around 20 years ago by the Swedish Road Administration, now known as the Swedish Transport Administration (Helldin et al. 2023). Such structures are being designed for targeted species, mostly larger mammals and especially ungulates such as deer, moose, or wild boar (Helldin et al. 2023). These species are prioritized because they are most frequently involved in wildlife accidents, which are considered a major problem due to the high economic and social costs for both animals and people (Helldin et al. 2023). Another consideration is that those species are placing higher demands on the crossings that come from their alertness and stringent requirements for a sense of security, openness, and naturalness (Helldin et al. 2023). Thus, they often function as umbrella species, addressing the needs of a wide variety of other animals (Helldin et al. 2023).

It is often emphasized, that developing mitigation plans should start with avoiding and minimizing impacts whenever possible and only then proposing a mitigation measure (Smith et al. 2015). This is because mitigation measures do not completely solve the problem, and the barrier effect is kept, although its impact on wildlife is reduced (Smith et al. 2015). Research suggests that wildlife crossing structures are an effective and realistic solution to barrier effect and habitat fragmentation (Smith et al. 2015). WCS together with fencing acts as a successful measure to reduce wildlife fatalities on roads, keeping animals off roads and funnelling them toward the crossing (Smith et al. 2015, Knufinke et al. 2019).

4.5.1 Sandsjöbacka ecoduct – an example of a successful WCS

A wildlife crossing structure that caught my attention is a fauna passage at Sandsjöbacka rising, stretching above the E6 road in Sweden. The ecoduct immediately captured my interest due to its visual separation of habitat zones, including so-called furniture, and the absence of high vegetation.

Those design considerations have been proven beneficial for ungulates (Smith et al. 2015, Denneboom et. al 2021).

Figure 9 View from E6 towards the north. Newly built ecoduct, May 2018 (Mats Lindqvist)

The ecoduct, which measures 32 x 64 meters, began construction in August 2016 and opened in June 2018. It provides a safe passage between wildlife's habitats, aiming to mitigate the barrier effect created by the E6, a major European high-speed road (Swedish Transport Administration 2018). Speed limits set at 100 km/h, along with traffic volumes varying between 45,000 and 60,000 vehicles per day, contribute to the barrier effect, making the road a significant obstacle for both humans and animals due to heavy traffic and fencing (Swedish Transport Administration 2018). The ecoduct connects Halland's largest nature reserve on the east with the Natura 2000 area and heather-covered Sandsjöbacka on the west side (Swedish Transport Administration 2018). People use the ecoduct, although no vehicles are allowed (Swedish Transport Administration 2020). Thus, it is widely visited by people to access hiking trails and to spend time outdoors (Swedish Transport Administration 2018). Information boards are placed right at the entrance to the crossing on both sides of the ecoduct (Swedish Transport Administration 2020).

Figure 10 West to the east view of the ecoduct with newly planted vegetation and various small biotopes, May 2018 (Mats Lindqvist)

The placement of the ecoduct was based on the ecological relationships, animal movement patterns, topographical factors, and opportunities for good adaptation to the landscape (Swedish Transport Administration 2018). Research and monitoring of the crossing were conducted for the 5 years after installation and some of the reports are already available, while the initial care of the plantings was planned to be conducted during 2018-2022 (Swedish Transport Administration 2020). The plantings were watered for the first two years to root well into the ground (Swedish Transport Administration 2020).

The screens meant to reduce disturbance introduced by traffic lights and vehicle noise are approximately 2.2 meters. The screening continues about 15-20 meters into the terrain, further limiting the disturbance for the animals (Swedish Transport Administration 2020). The fence nearest to the ecoduct is buried in the ground to prevent animals from digging under it and reaching the road (Swedish Transport Administration 2020).

Figure 11 Fencing buried in the ground to prevent wildlife from digging their way out to the road (Mats Lindqvist)

There are small biotopes and furniture designed to enrich biodiversity, benefiting wildlife (Swedish Transport Administration 2020). They consist among others of dead wood, stumps, and sandy areas as well as rock cairns and wetlands to support a variety of wildlife species (Swedish Transport Administration 2020). The plants have been chosen based on the needs of animals, especially regarding food and shelter (Swedish Transport Administration 2018). No trees were situated on the crossing itself but over 100 trees were planted nearby (Swedish Transport Administration 2018). Thousands of bushes and herbs were planted to benefit various animals, and even more were sown (Swedish Transport Administration 2018). The created landscape is not supposed to be static but ever-changing due to factors such as climate change, animal grazing and management efforts (Swedish Transport Administration 2020).

The ecoduct was designed to be used by roe deer, moose, fallow deer, and wild boar, all of which inhabit the nearby area and successfully use the WCS (Swedish Transport Administration 2020). Moreover, smaller species are planned to benefit from the structure, such as foxes, mice, badgers, hares, reptiles, and bats (Swedish Transport Administration 2020).

The ecoduct has been proven to work in the intended way, accommodating targeted species (Swedish Transport Administration 2020). Thus, the design elements can function as a recommendation for successful WCS. The ecoduct, unlike a regular overpass with narrower dimensions, allows for the representation of a wider variety of habitats, thus targeting more species. Moreover, the “furniture” on the ecoduct provides resources for wildlife users (Smith et al. 2015).

4.6 Wildlife Habitat Relationship (WHR) method

Wildlife species are predetermined to inhabit a specific landscape category and the unique elements within them (Clevenger et al. 2009 see Denneboom et. al 2021). Therefore, species-specific preferences regarding wildlife crossing are expected to vary. Research results in support of this hypothesis incline that structures resembling the natural environment of selected species are preferred by wildlife (Denneboom et. al 2021). Such environments are referred to as habitats, composed of elements well known to landscape architects such as plant communities, soil type and moisture, climate, and weather. Habitat is a species-specific concept, with every species having a particular set of requirements (Krausman & Morrison 2016). Therefore, habitats are inherently in support of species survival and reproduction (Krausman & Morrison 2016).

Habitat types, which include vegetation communities and other land cover have various suitability utilities for each species, reinforcing the idea that wildlife habitats are species-specific (Beck & Suring 2009; Verboom & Pouwels 2004 see Greco n.d.). WHR models represent the ecological requirements of single species by dividing habitat into different functional units based on various aspects of species’ life units (life requisites) which include feeding habitat, cover habitat, and reproductive habitat (Cooperrider, 1986 see Greco n.d.). WHR comes from a theory in ecology and can be referred to as “resource selection functions” (Noss, O’Connell, & Murphey, 1997 see Greco n.d.).

A crucial aspect of WHR models is the existence of specific habitat elements or habitat components within the site that are vital for the survival and long-term sustenance of the species (Cooperrider, 1986, Table 1, p. 760; CDFW, 2014a, p. 13-14 see Greco n.d.). Such elements can be living or dead resources, for example, rock piles for reptiles, and often site visits are required for their mapping and analysis (Greco n.d.). WHR can be utilized to estimate the environmental impact of a development or industry, for example, timber harvest or to design functional environments for targeted species, including wildlife corridors connecting habitats for ungulates

(Greco n.d.). Such corridors should be functionally connected which means that they consist of habitat types observed to be used by a species for migration and in that way differs from structural connectivity (Greco n.d.). Therefore, proper connectivity is species and landscape-specific (Noss, 2006, p. 71 citing Bennett, 1999 see Greco n.d.). Corridor width might be determined by ecological function and habitat requirements, although it is important to note that such criterion is not yet specified but is planned to be studied in the future (Greco n.d.). Therefore, the aim of using the method in this paper is to investigate landscape systems and ecological concerns on a regional or municipal scale and to use WHR models in planning for functional habitat and movement corridors.

4.7 Moose

Figure 12 Moose (Bruno Balestrini, Qbert88)

The range of *Alces alces* (moose) stretches from the eastern to western hemisphere and the species can be found north of the latitude 40°N (Niedziałkowska et al. 2022). *Alces alces alces*, the European moose, inhabits Eurasia including Norway, Sweden, Baltic states, Poland, Belarus, Finland, Russia, and Ukraine and is the targeted species in this thesis.

As the largest species from the deer family, they can weigh up to 650 kg and reach a height of 2 meters. Even with the large size in central Scandinavia, the animal species is the dominant prey for wolves (Canis lupus, Sand et al. 2012 see Niedziałkowska et al. 2022). Furthermore, Scandinavian individuals when confronted with people or human activities are generally not aggressive and less bold than moose in North America (Niedziałkowska et al. 2022). They can adapt to their environments by spatiotemporal patterns; thus, moose is a flexible species in their preference for habitat if it offers opportunities for abundant foraging and forested shelters (Bjørneraas et al., 2011 see Janík et al. 2021). Moreover, studies showed that the highest activity of moose occurs during dusk and dawn, being characterized by seasonal and diurnal activity patterns (Neumann et al. 2012 see Niedziałkowska et al. 2022).

4.7.1 Migration and movement patterns

Many moose populations migrate seasonally to mitigate the winter food shortages. Lack of migration is mostly observed in isolated or homogenous habitats (Niedziałkowska et al. 2022). In southern Sweden, individuals tend to migrate around 5 km a day (Singh et al. 2012 see Niedziałkowska et al. 2022). Home ranges depend on animal sex, age, quantity and quality of forage, reproductive status and weather conditions and account for between 10 to 60 km2 (Beest et al., 2011; Cederlund & Sand, 1994; Murray et al., 2012 see Janík et al. 2021). During their migration, they often come across barriers such as roads where they are prone to be impacted by traffic-associated mortality (Seiler 2005 see Janík et al. 2021). Thus wildlife-vehicle collisions are an increasing problem for herbivore populations (Bragina et al. 2018; Mrlík, 1995; Ree et al. 2015 see Janík et al. 2021).

For maximization of individual fitness, the home ranges of moose are often different in summer and winter (Borowik et al. 2020). Wetlands are the habitats preferred in summer and forests in winter (Borowik et al. 2020). If summer ranges have a sufficient number of supplies in winter the migration is less likely to occur, and the best supply of winter habitat is found in coniferous forests (Borowik et al. 2020). Thus, the migratory behaviour is believed to decrease in case of forest abundance in summer home ranges (Borowik et al. 2020). Individuals often move to neighbouring feeding grounds in the spring but retain a connection with their winter home range, visiting them regularly (Borowik et al. 2020).

4.7.2 Feeding habitat

Moose are well adapted to water environments, where they can swim several kilometres and even forage underwater with closed nostrils (Niedziałkowska et al. 2022). Foraging on wetlands and nearby water bodies is crucial for the species' survival (Borowik et al. 2020). During springs, moose prefer seral forests, which are sparsely forested and have a rich cover of deciduous shrubs providing browsing (Courtois et al., 2002 see Janík et al. 2021). In Eurasia, their diet includes about 250 plant species (Dzięciołowski and Pielowski 1993 see Niedziałkowska et al. 2022) which include lichens, grass, ferns, herbs, shrubs, and trees. It is important to stress that some plant species consist of most of the moose diet and those are woody plants which make it possible to forage all year around (Renecker and Schwartz 1997 see Niedziałkowska et al. 2022).

The forage availability influences the energy intake by ungulates, thus even small enhancements in vegetation quality can lead to significant impacts on moose body mass and reproduction (White 1983 see Holmes et al. 2021).

Species	**Taxa**	**Type**
Scots pine *Pinus sylvestris*	*Betula, Salix, Pinus, Sorbus, Rosa and Vaccinum*	lichens, grass, ferns, herbs, shrubs, and trees
Aspen *Populus tremula*		
Juniper *Juniper communis*		
Willow *Salix sp.*		
Rowan *Sorbus aucuparia*		
Silver birch *Betula pendula*		

Table 4 Most frequently eaten plants by moose (Dzięciołowski and Pielowski 1993 see Niedziałkowska et al. 2022, Hörnberg 2001a see Malmsten 2014)

4.7.3 Cover habitat

Good adaptation to cold temperatures is well evident in moose, whereas their intolerance to heat creates their dependency on water bodies as well as dense and mature forests to cool down and mitigate heat distress (Bjørneraas et al., 2011; Dussault et al., 2004 see Janík et al. 2021). The thick fur filled with air creates isolation, thus low thermal radiation means that the species suffers because of high temperatures but thrives in low temperatures (Svensson 2008 see Niedziałkowska et al. 2022). They inhabit closed forests, especially mature coniferous forests, to seek cover (Beest et al., 2012; Melin et al., 2016 see Janík et al. 2021).

4.7.4 Reproductive habitat

One of the biggest factors affecting reproduction is forage availability (Sand et al., 1996 see Malmsten 2014). During the rut season, moose males patrol vast landscapes searching for available female mates (Cederlund & Sand, 1994 see Malmsten 2014). In tundra regions, females typically form assemblages in open landscapes to attract males of various ages (Schwartz 2007 see Malmsten 2014). This thesis assumes that similar behaviour occurs in other regions, indicating that some populations require open land for successful reproduction.

Female moose need to keep sufficient body mass to deliver young calves (Milner et al. 2013 see Holmes et al. 2021). Thus, food sources and wildlife reliance on them are critical. Moreover, moose calves need landscapes which will sustain them throughout harsh years, which includes forage and thermal cover opportunities (Holmes et al. 2021). Even a slight improvement in vegetation quality can lead to significant impacts on weight gain and/or the likelihood of conception (White 1983; Cebrian et al. 2008 see Holmes et al. 2021).

4.8 Sustainable urbanization

The notion of sustainable urbanization has increasingly gained heightened attention (Telsaç and Kandeğer 2022). In contrast to economic-based developments, it prioritizes the addition of social and environmental approaches.

Oxford Dictionary describes sustainability as

"The property of being environmentally sustainable; the degree to which a process or enterprise is able to be maintained or continued while avoiding the long-term depletion of natural resources" (Oxford English Dictionary 2023).

Urbanization is described as

"the process in which towns, streets, factories, etc. are built where there was once countryside" (Oxford English Dictionary 2023).

The intersection of both definitions delivers a meaning that it is a development from rural to urban made without harmful effects on nature or the environment (Telsaç and Kandeğer 2022). Therefore, future generations should have as many biophysical resources and opportunities supplied by the ecosystems within the future cities as we do now (Telsaç and Kandeğer 2022).

4.8.1 Urban sprawl

Urban sprawl is one of the urbanization types and is characterized as an automobile-dependent area with modified travel mode and pattern, that is of low-density and spatially segregated (Yasin 2020). It is often defined as undesirable and is associated with excessive resource consumption (Yasin 2020). Generally, urban sprawl occurs in sparse and low-density units and is an expansion of the urban periphery (Yasin 2020). Therefore, it represents an urban development pattern with the greatest influence and occurs at an extraordinary rate threatening sustainable urbanization (Yasin 2020). Therefore, such developments have the potential to cause the absorption of rural, agricultural, and environmentally fragile land (Deilami & Kamruzzaman 2017; Nope et al. 2020 see Yasin 2020).

Other characteristics of urban sprawl are traffic volumes and travel modes, and they are correlated to urban land use (Yasin 2020). Upgrading regular roads into high-speed and capacity expressways enables people to commute over greater distances between residential areas and urban centres (Yasin 2020). Such infrastructure heightens automobile dependency and lowers accessibility to public transport which struggles to provide services in low-density areas (Yasin 2020). Another factor that contributes to the aforementioned effect is that urban sprawl is downgrading mix-use developments into segregated single uses and therefore reduces the efficiency and functionality of urban land systems (Yasin 2020). Urban sprawl expanded from simple residential areas towards more intricate landscapes featuring diverse land uses, dispersed industries, and multiple centres (Silva and Ma 2021). It is important to emphasise that urban sprawl to be categorised as such may have one or more of those characteristics, although the complex nature of the phenomenon causes the evaluation to be difficult and rather a continuum than specialized or generalized characteristics (Yasin 2020).

There are economic, social, political, and environmental consequences to urban sprawl (Yasin 2020). In this thesis, special focus is paid to environmental effects. Degradation is the most important cost correlated with urban sprawl and intensifies due to the pattern and characteristics of this kind of urbanization. Urban sprawl decreases forest, agricultural and open space land (Yasin 2020). Low-density and scattered housing requires substantial infrastructure, such as a road network which further fragments the habitats (Yasin 2020). The fragmentation that is associated with urban sprawl causes ecosystem disruption such as imbalances in food chains and biodiversity loss (Yasin 2020). Therefore, based on the characteristics of urban sprawl it is concluded to be a threat to sustainable development (Yasin 2020).

5. Site analysis

5.1 Geographical context

The wildlife crossing is located south of Stockholm in Nynäshamn municipality (Fig. 13). It comprises a rich and diverse natural environment, which includes the archipelago coast, ancient landscapes, vast forests, many lakes, and waterways. Forests are filled with abundant life and signs of many wildlife inhabitants. The hilly Rift Valley landscape, characterized by wooded areas and meadows, serves as a habitat for rare species, with ongoing protection plans in place (Nynäshamn municipality 2024c). Preservation of those precious environments, especially due to rapid development, should be prioritized.

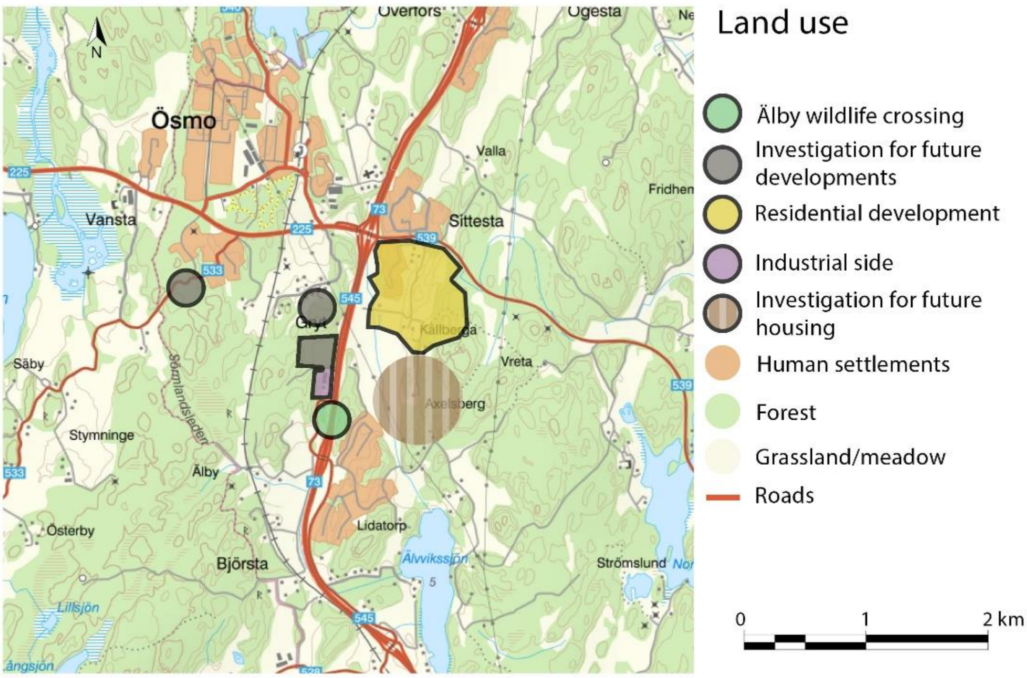


Figure 13 Map of land use around the crossing (map source: Lantmäteriet, modified with input from Nynäshamn municipality 2024c)

The National Road 73 which cuts through the municipality creating a barrier effect, was finished in 2010 (Swedish Transport Administration 2020).

It was a major project for the Swedish Transport Administration and a lot of resources were invested to further project sustainability. The speed limit around the overpass equals 110 km/h and is the highest within the whole road. Higher speeds tend to produce more noise and disturbance for animals mainly due to friction between tyres and asphalt (Wikipedia contributor 2023). Along Road 73 the Älby business area is located and lies between Lidatorp and Ösmo. Currently, the area consists of 10 hectares but is planned to be expanded to an additional 6-8 hectares (Nynäshamn municipality 2024c). It is proposed to introduce further developments toward the north. Those sites are represented as industrial sites and developments on the land use map. Smaller towns such as Lidatorp, Källberga and Björsta (Fig. 14) will be developed through new business establishments, plots, and services and jointly they will create an agglomeration (Nynäshamn municipality 2024c). Thus, connecting them is planned by the municipality with public transport, pedestrian, and bicycle paths. Building and developing transport infrastructure between those towns might fragment the environment and pose a risk to wildlife habitat connectivity.

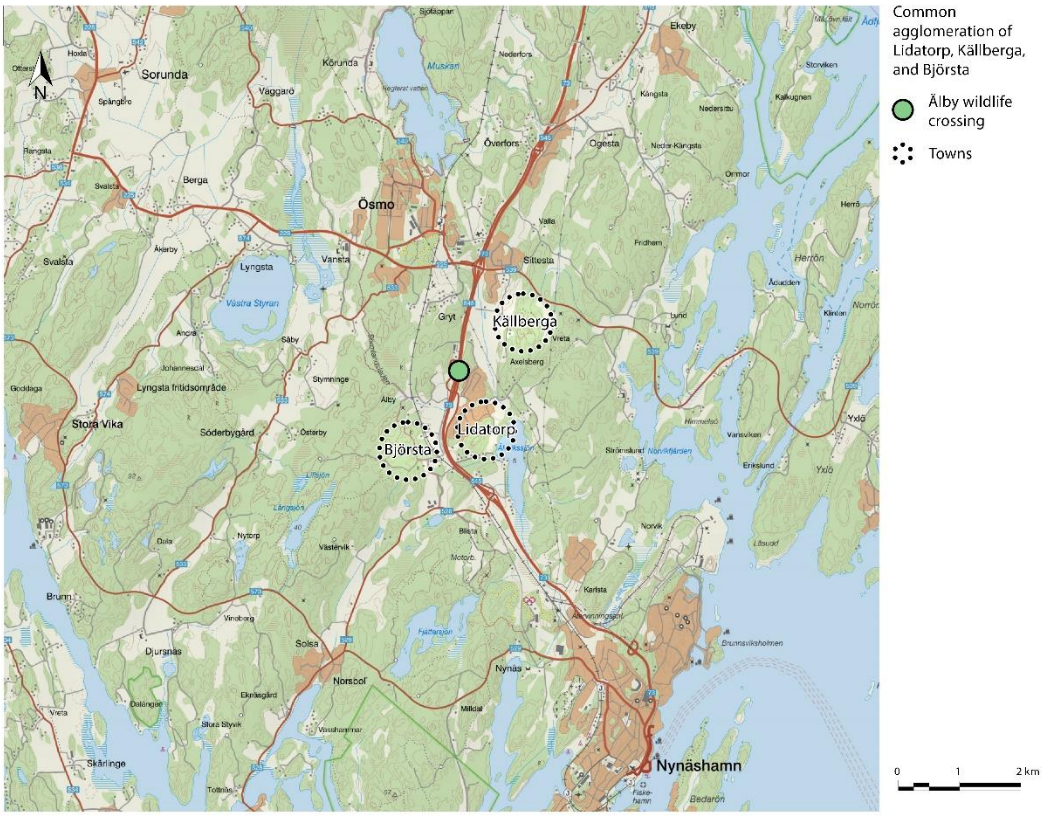


Figure 14 Map of planned agglomeration (map source: Lantmäteriet, modified with input from Nynäshamn municipality 2024c)

5.2 Analysis of moose movement and crossing possibilities

Depending on various factors, wildlife crossings in areas with barrier effect should be at a maximum every 6 kilometres, preferably more frequent than that (Trafikverket 2015). Barriers over 6 kilometres long have a remaining need for action according to the goals specified in Landscape guidelines (Trafikverket 2015). An analysis of nearby wildlife crossing possibilities was conducted with the usage of Google Earth.

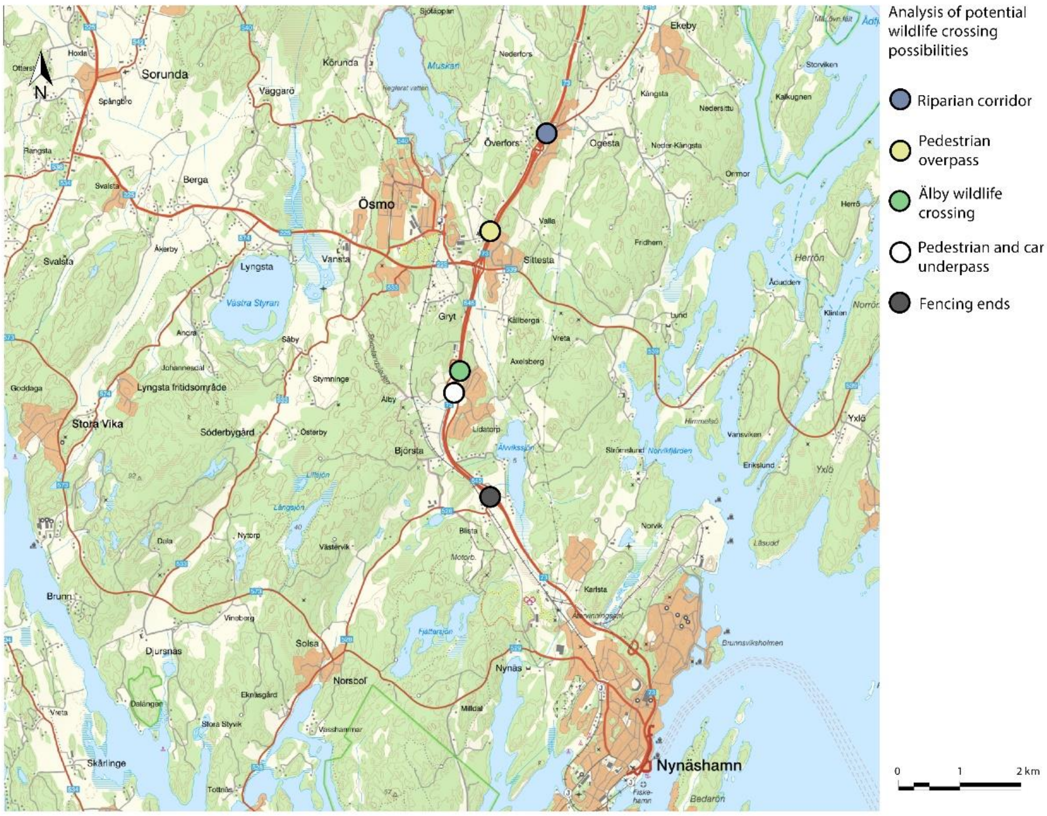


Figure 15 Analysis map of potential wildlife crossing possibilities (map source: Lantmäteriet, modified with input from Google Earth)

According to a conducted aerial map survey (Fig. 15), the closest potential crossing in the north is about 2400 meters from the WCS. It is a pedestrian overpass (Fig. 16) made with concrete flooring. Pedestrian and cyclist bridges might be a suitable crossing option for wildlife if they are large enough and at their entrance connect natural areas in distance from human settlements (Ree and Grift 2015). Paved surfaces and human usage during the day do not exclude wildlife usage during the night (Seiler et al. 2015). Therefore, the structure could potentially be used by wildlife in times of human absence, although it might not be preferred by moose.

Figure 16 Pedestrian bridge on Road 73 (Google Earth; Street View)

Another crossing is located about 4200 m north. It is an underpass located in a riparian corridor (Fig. 17) with both crushed stone and vegetation on the sides of the water stream, which allows wildlife use, for crossing under the highway. The limitation of this crossing might be a low ceiling under the highway, unfortunately, exact measurements could not be acquired. The noise-reducing screens are low and are not applied in the middle clearance which might introduce excessive noise for wildlife. Both limited vertical spaces, as well as noise and light pollution, are especially impacting moose. Spaces designed for their accommodation need to be big enough to be comfortable for them, the physical ability to fit in them is not enough (Smith et al. 2015).

Figure 17 Underpass, Road 73 (Google Earth; Street View)

South of the WCS, 340 meters away, under the highway there is an underpass for pedestrians, cars, and bicycles (Fig. 18). It is an important connection node for people. The underpass was visited during the site visit and no intentional accommodation for wildlife was observed. Surprisingly, ungulates used it, as Fallow deer hoof prints were found on the opposite side of a pedestrian path. The underpass connects Lidatorp and the forest nearby with arable lands. It is surrounded by road nodes that lead to the highway and have high-speed limits which brings a question regarding drivers and animal safety. The underpass has clear views and lacks vegetation at the entrance. Although ungulates generally prefer underpasses with vegetation at the entrance (Clevenger and Waltho 2005; Denneboom et al. 2021) and have a slight preference for overpasses (Ruediger and DiGiorgio 2007; Denneboom et al. 2021), some still used this crossing to move between habitats.

Figure 18 Underpass connecting the old Nynäsvägen with Klövstavägen

Fencing (Fig. 19) stops around 2400 meters south of the crossing. The speed limit remains high after the fencing ends and natural habitats near the road are probably used by wildlife. The road sign informs that wildlife fencing ends. Lack of fencing means better connection for wildlife but also potentially higher wildlife accident rates.

Figure 19 Fencing ends (Google Street View)

In Sweden, it is mandatory to report to the police any accident involving larger wildlife species, regardless of whether the animal was hurt, injured or not. The location is marked to the creation of the database and not reporting is punishable (Nynäshamn municipality 2024b). Consequently, an analysis of moose mortality between 2018 and 2022 was created to research the correlation between crossing possibilities and areas where species are crossing the roads in unsafe environments.

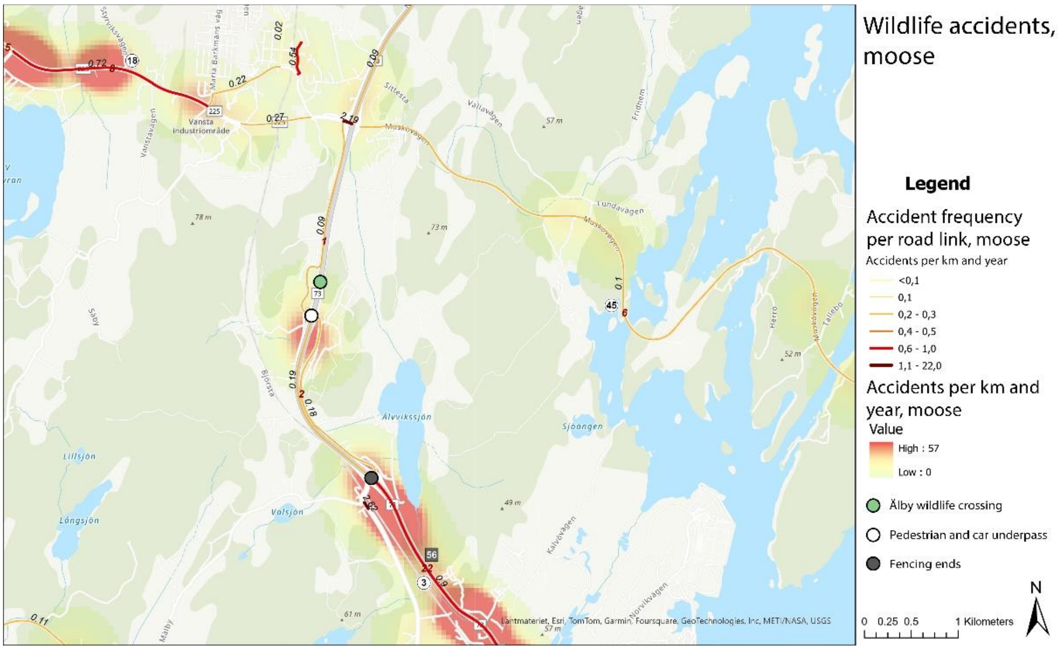


Figure 20 Wildlife accidents, moose (data source: Swedish Transport Administration, created by me)

Crossing opportunities north of the WCS do not exhibit an increase in moose mortality. Conversely, southern alternatives to WCS spike in species mortality, which is in line with crossing characteristics. Underpass and high-speed roads are not safe for wildlife which should be discouraged from using those spaces to cross the road and be redirected to use Älby WCS. Fencing is interrupted due to road intersections, which creates an unsafe environment for wildlife and humans. Therefore, southern crossings are not a sensible option for wildlife and that creates even stronger reliance on the Älby WCS. Moreover, nearby roads, excluding Road 73, lack fencing and constitute a hazard to wildlife safety.

5.3 Urbanization of Nynäshamn Municipality

The development of transport infrastructure tied the Nynäshamn municipality to Stockholm and the integration opened the housing and labour markets, creating a surge of urban sprawl. There is ever-growing interest in the housing market which the municipality tries to tackle with its proposed plan. Therefore, the municipal goals for housing developments and increasing its population are evident in a new housing development close to the wildlife crossing in Älby. I attempted to examine the municipality's urbanization scheme critically and evaluate ways moose populations and habitats could be protected.

5.3.1 The Lidatorp town

The Lidatorp town is located east of road 73 and in between Nynäshamn and Ösmo. The town is approximately six kilometres from Nynäsgård station and four kilometres from Ösmo station. It is the only residential area directly connected with the WCS in Älby and even has a hiking path connecting the town with the overpass. Most of the buildings in the town were built at the beginning of the 2000s (Nynäshamn municipality 2024c).

Public transport connecting the town with Stockholm is not reliable, trains are frequently cancelled, and it appears that many people choose to commute to work with private vehicles. Moreover, the site visit revealed that inhabitants are indeed car-dependent. The town contains housing exclusively and lacks other services such as preschool, workplaces, services, and possible meeting places. The houses have relatively small gardens which are separated with fences or hedges, while the entrance from the road is usually not fenced, making a more welcoming and communal impression. Consequently, wildlife could potentially move through the landscape as no high fences are installed. The development is concluded to be part of urban sprawl in the region.

Figure 21 Lidatorp town (Jakub Kubala)

There is a path leading from the cement plant to the crossing (Fig. 23) which is used for leisure. The overpass appears to be used predominantly for leisure and sport, especially since the area is quite hilly and is suitable for mountain biking. Moreover, more accessible human crossing options are available in the surroundings, such as nearby underpasses. Leisure activities are most likely conducted exclusively by the local inhabitants.

Figure 22 The path from the cemetery plant toward the overpass goes through the hilly

5.3.2 Källberga

One of the new developments planned north of Lidatorp, is Källberga (Fig. 13). It occupies 74 ha of land and lies on the crossing of Road 73 and Muskövägen. It is located two kilometres from the town of Ösmo, the second biggest in the municipality. An important characteristic of the development is the closeness to Stockholm which is estimated to take only 25 minutes by car.

Currently, 600 to 700 houses are planned with aspirations for future expansion of another 500. The development is planned with five stages starting in 2021 and finishing in 2030. The stages progressively move from west to east claiming more land for the low-density housing.

The planning area "Källberga" in its current form is located approximately 1 kilometre from the wildlife crossing and planned developments will be as close as 600 meters and might dramatically increase the visitorship and human disturbance around the overpass by 2030. Detailed planning work for the new developments was set to start in 2023-2024 and includes a maximum of 600 houses (Nynäshamn municipality 2024c). According to the planning documents, there will be a maximum of 1200 apartments in the area, and assuming that 2.5 persons inhabit one apartment, which is probably a low estimate, it will create a population of 3000 new inhabitants (Nynäshamn Municipality 2024c). Moreover, the municipality anticipates a population increase, projecting 36,000 inhabitants by 2040, up from 30,311 in 2023—an increase of around 5,500 residents (Nynäshamn Municipality 2024c, SCB, The Statistics Authority 2024). Authorities claim that planned developments focus on the densification and urbanization of existing areas like Nynäshamn and Ösmo to achieve sustainable growth (Nynäshamn municipality 2024c). Such an approach is confirmed to be a good approach as sparing large areas of land from urbanization is the best attitude toward biodiversity loss and helps to maintain a healthy ecosystem that benefits both nature and people (Soga et al. 2014). Interestingly, Källberga development alone has a maximum capacity of meeting 55% of the municipalities goal. Källberga is expected to play a significant role in the region's population growth. However, this expansion is anticipated to be far less sustainable than the densification efforts promoted by local authorities as the primary driver of population increase. Therefore, limiting the Källberga development is a sensible solution to habitat fragmentation.

Therefore, the development exhibits characteristics ascribed to urban sprawl, such as car dependency, low-density housing units, and an expansion of the urban periphery (Yasin 2020). Sparsely urbanized areas will claim wildlife habitats and create a barrier effect. One of the biggest impacts of the development lies in limiting the connection between WCS and the habitats southeast.

5.4 Natural and cultural values

The municipality has a rich and diverse natural environment. It consists of a long archipelago coast, old cultural and agricultural landscapes, many lakes, and waterways as well as forests. The protection of those environments is of high importance.

Environmental Impact Assessment (EIA) was concluded in Källberga by Iterio (2018) which specified that species value in the area is judged to be "insignificant". Due to the loss of greenery, compensation measures will be taken (Iterio 2018). The nature inventories do not mention large mammals, ungulates, or other wildlife of similar kinds. It means that the development impact of those wildlife populations has not been measured and taken into consideration while planning. One of the main impacts is evident in the land loss to the Källberga development, as the area was providing habitat to wildlife. Additionally, the development will cause fragmentation of habitats and limit the range of wildlife.

The municipality has plans to protect the area immediately to the west-south of the crossing (Nynäshamn municipality 2024c). It is classified as class 3 out of 4, with 1 being the highest priority for protection. It has been called “Älby gravel estate” and includes the abandoned cemetery plant and dry slopes around it. Rare insect species were found there, including the cinnabar moth (*Tyria jacobaeae*) which is reliant on rare plant species that grow in the area such as (*Jacobaea vulgaris*) whose patches were found in the area and along route 73. Other red-listed species were observed there in 2015 after an inventory made by the Swedish Transport Administration. The land is prevented from developing canopy cover which would threaten the biodiversity. Such protective actions as well as municipalities' decisions about protecting this area from future development are crucial to the functioning of the WCS. It ensures no disturbance in the closest surroundings of the crossing and also contributes to the immediate surroundings of the crossing being rich and lush.

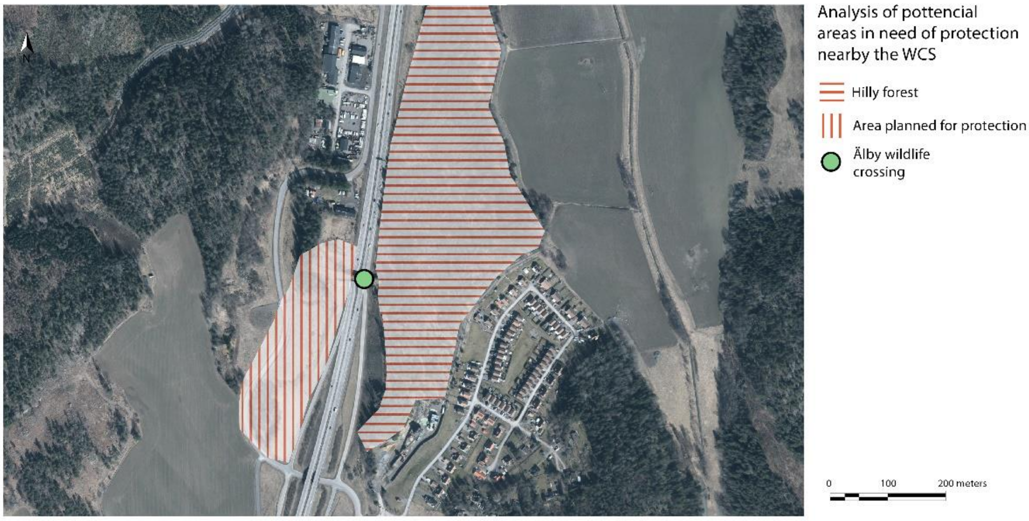


Figure 23 Analysis of physical disturbance near the overpass (map source: Lantmäteriet, modified with input from Nynäshamn municipality 2024c)

The eastern entrance to the crossing is hilly and forested with a small chance for any development happening there. Excessive visitorship to the area might disturb wildlife populations, although as long as it is consistently happening within the day and the area is left with a minimal number of visitors at night it may not pose a threat to wildlife confidence in the area (Ree and Grift 2015, Knufinke et al. 2019). Thus, site characteristics are in favour of wildlife and should be further protected.

The topography within the focus area is characterized by a hilly rift valley landscape, which is typical for Södertörn region. Elevated areas are wooded while plains are mostly covered by meadows and agricultural land. Older trees, particularly evergreens like pines, are prevalent in forests. Cherry and birch can be found frequently. Other species such as willow, aspen, oak, ash, and wild rose occur nearby. Ferns and blueberry bushes have been found within the forest. Plant species found in the Källberga include Lingonberry *Vaccinium Vitis-idea*, Mountain fern moss *Hylocomium splendens*, and Stone bramble *Rubus saxatilis* which are valuable food sources for moose. Thus, the dietary requirements of moose are met in the area, as many of those plants are most frequently eaten by the species (Dzięciołowski and Pielowski 1993 see Niedziałkowska et al.2022). A mature and enclosed forest on the hill seems to be suitable to seek cover by moose and it can help to lessen the impact of heat on the animal. Nearby the crossing there are water bodies needed by moose. Ällvviksjön lake is the closest, only 1.15 km away from the crossing toward the southeast. It may play a significant role for the species, which needs water bodies for forage and to thermoregulate in summer.

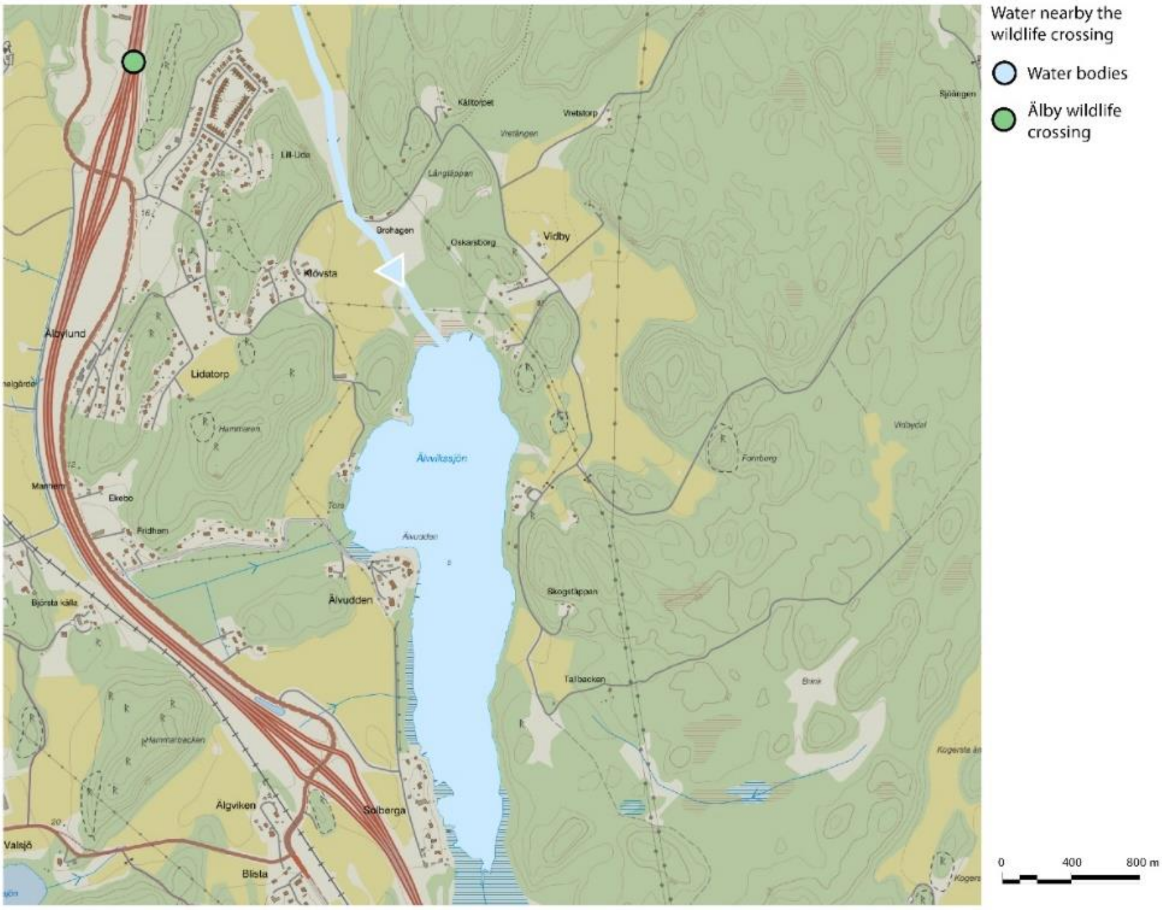


Figure 24 Water near the overpass map (source: Lantmäteriet, modified by author)

5.5 Analysis of overpass users and the feasibility of integrating human and wildlife usage

To assess the feasibility of human and wildlife co-usage of the overpass, data regarding time usage was analysed, to determine if there is time separation. Moreover, the share of species using the crossing and mortality of those species in Nynäshamn municipality were analysed. Such analysis aims to provide clues on which species are disadvantaged with the current design of the crossing.

Consequently, the collected data reinforces the suitability of choosing moose as an umbrella species. Not only did moose percentage share in the death toll rise from 2022 to 2023 from around 8 per cent to 10 per cent

(National Wildlife Accident Council n.d.), but a disproportionate number of moose die in car accidents compared to the makeover of the species using the crossing. In 2023 10 per cent of reported roadkill was constituted by moose and only 1 per cent of the crossing users in a year period between 2019 and 2020 (National Wildlife Accident Council n.d. and Triekol n.d.). Thus, moose were killed more often than, for example, fallow deer but used the crossing less often.

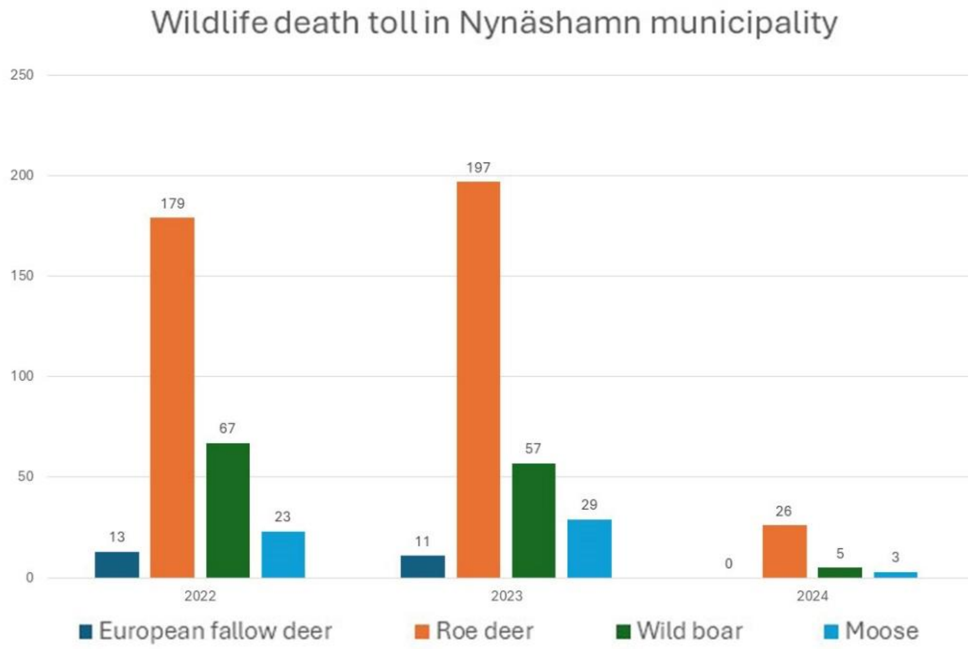


*Table 5 Wildlife death toll in Nynäshamn municipality (*source: *National Wildlife Accident Council n.d.*, created by me*)*

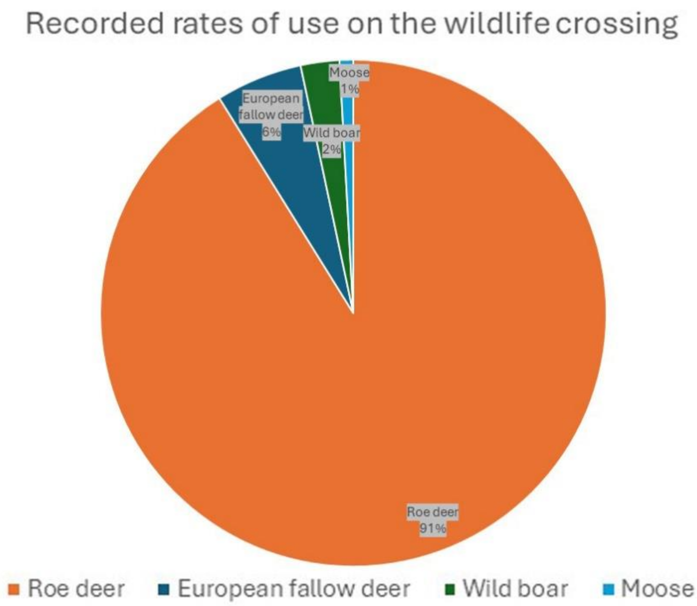


*Table 6 Share of species in usage of the overpass (*source: *Triekol n.d.*, created by me*)*

Additionally, time separation was analysed based on WCS usage data. The most frequent hours for people to visit the crossing were 12 to 16 (Table 7). Generally, people avoided the crossing before dusk and after dawn (Table 7). The most frequent hours of wildlife usage were from 17 to 6 (Table 8). It means that animals portray nocturnal preference which generally corresponds to low human disturbance.

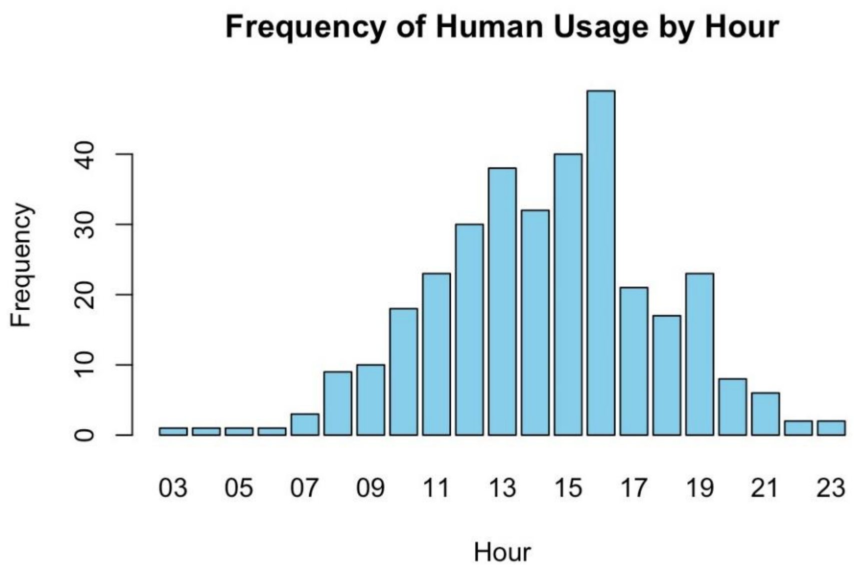


Table 7 Frequency of human usage by hour (source: Triekol n.d., created by me)

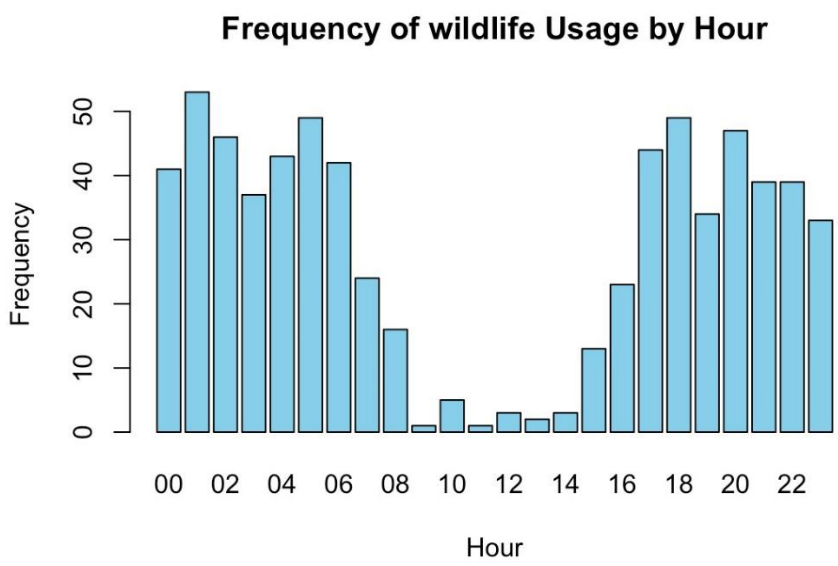


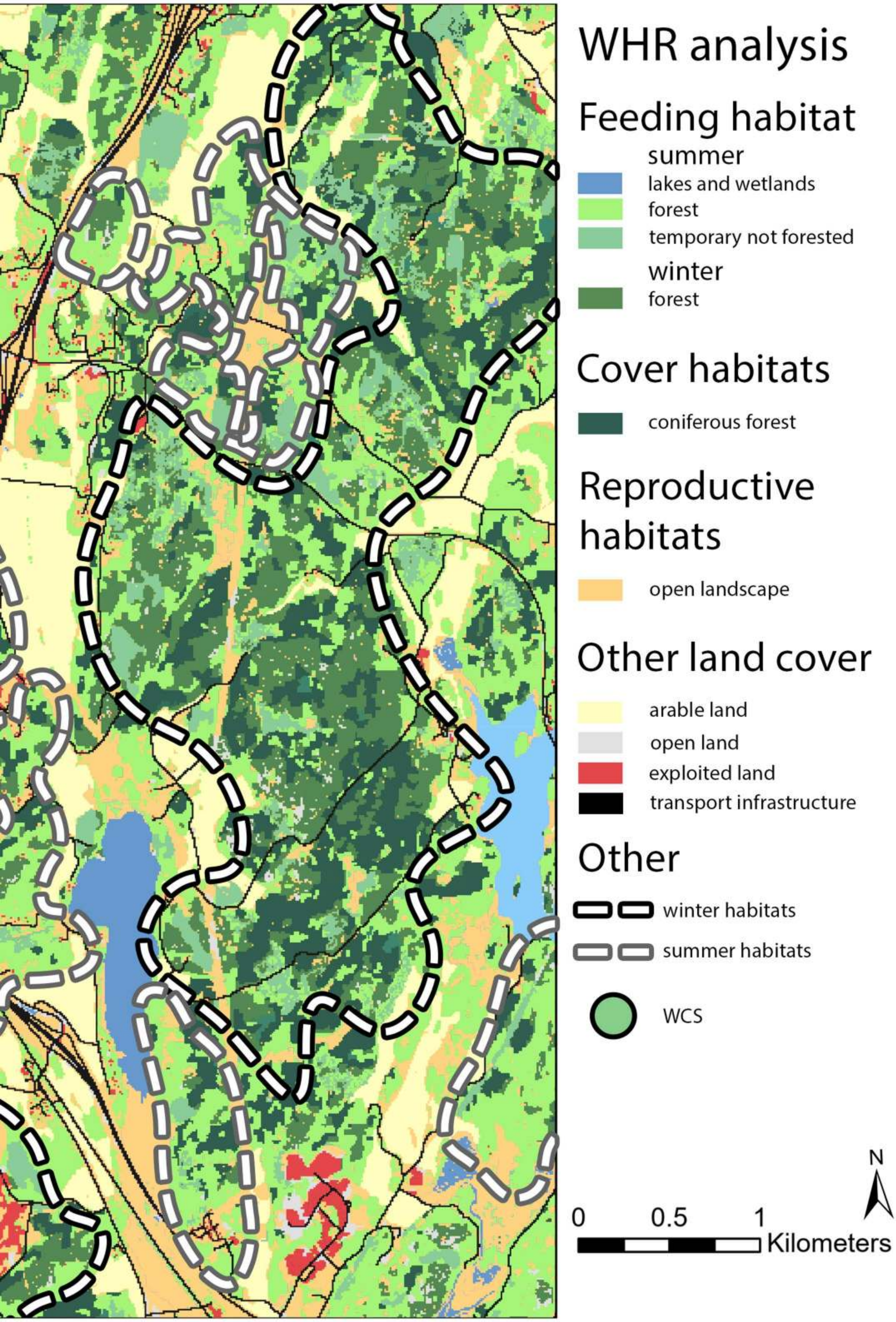
Table 8 Frequency of human usage by hour (source: Triekol n.d., created by me)

Therefore, there is a time gap between human and wildlife usage when animals can use the crossing undisturbed. It proves that separation in time occurs, and sustainable human usage might be possible (Knufinke et al. 2019).

5.6 WHR analysis

The WHR analysis aim is to locate moose core habitats, especially those used in summer and winter. Then, the connection between those areas was analysed. Habitats are divided by feeding, cover and reproductive categories. Major patches of summer and winter-feeding habitats were marked. The map highlights that many habitats are fragmented by transport infrastructure (colour black – transport infrastructure Fig. 25), and areas with higher rates of vehicle mortality correlate with those where habitats have been fragmented. Moreover, there is a strong connection between habitat categories, as cover habitats are within feeding habitats and reproductive habitats are in between feeding habitats. East-to-west connection is of greatest importance, mostly because of strong barriers, and is facilitated by the Älby WCS. Consequently, Källberga's development is a threat to this connection.

Figure 25 Wildlife Habitat Relationship analysis (source: The Swedish Environmental Protection Agency, modified by au


WHR analysis
Feeding habitat
summer
lakes and wetlands
forest
temporary not forested
winter
forest
Cover habitats
coniferous forest
Reproductive habitats
open landscape
Other land cover
arable land
open land
exploited land
transport infrastructure
Other
winter habitats
summer habitats
WCS
N
0
0.5
1
Kilometers

uthor)

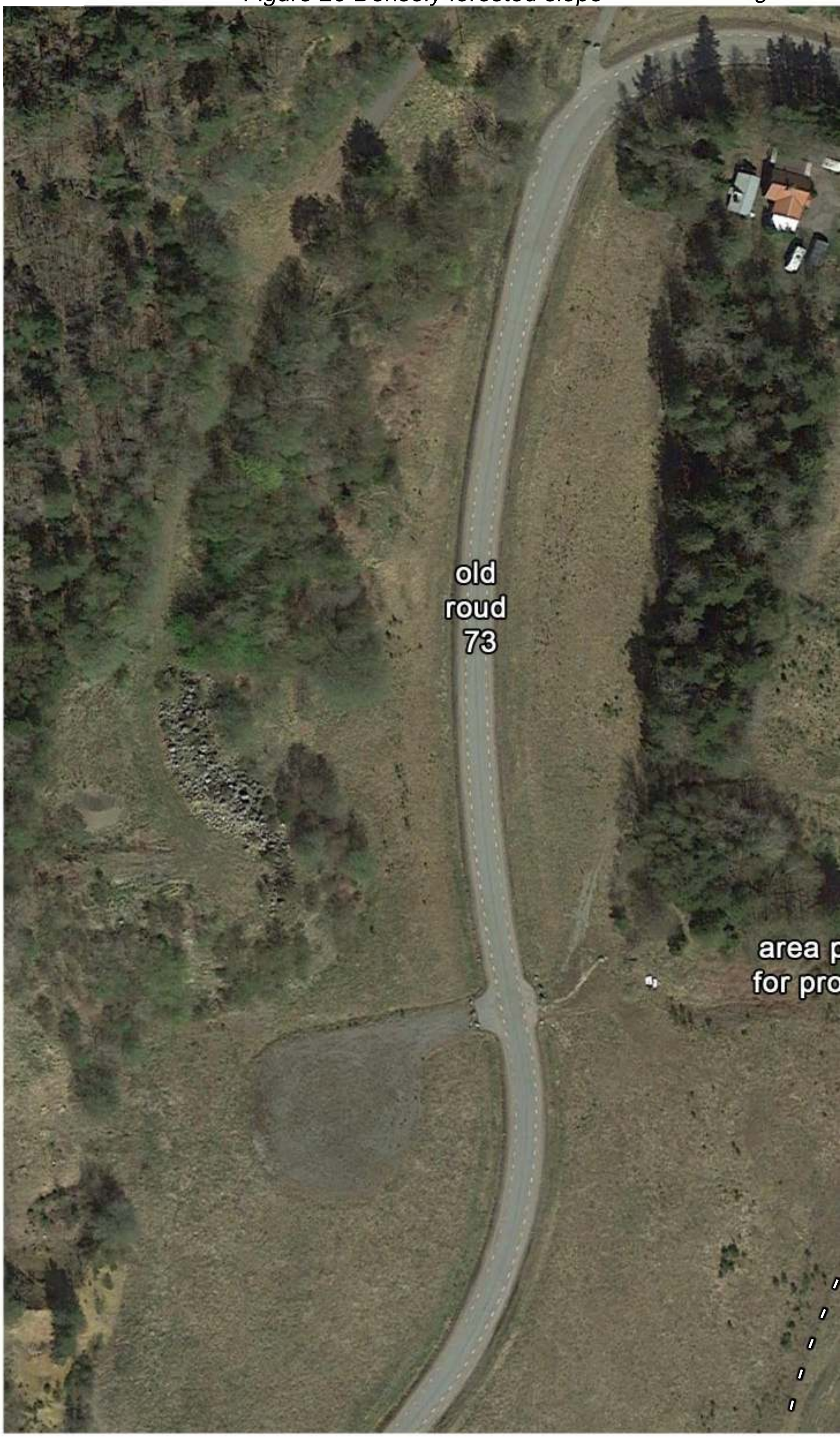
5.7 Overpass analysis - identification of design flaws and inefficiencies

The immediate surroundings of the crossing are currently undeveloped, though some plans suggest that this may change soon. While the western entrance, which includes protection measures, and the hilly eastern entrance are unlikely to see development, the planned Kallberga development poses a potential risk to both the wildlife and the functionality of the overpass.

The map highlights the proximity of Lidatorp to the crossing and the path that connects them (Fig. X). The forested hill (Fig. X) is denser along the slope but becomes sparser toward the top (Fig. X).

Figure 26 Densely forested slope

Figure 27



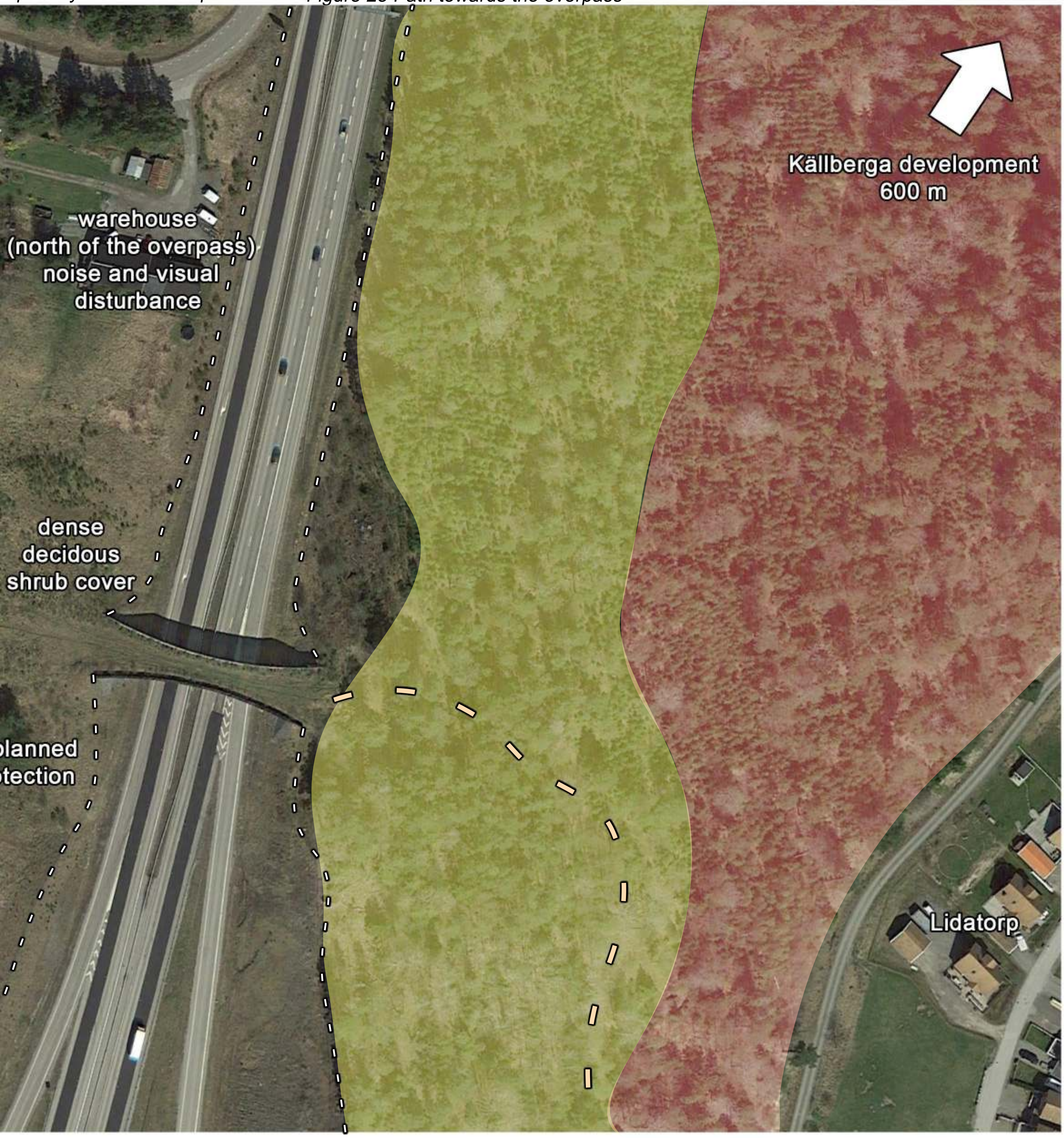
Land cover

- sparse forest on the hill top
- dens forest on the slope
- path leading to the overpass
- fencing

Figure 29 Overpass surroundings analysis (map source: Google Earth, modi

Sparsely forested hilltop

Figure 28 Path towards the overpass



fied by author)

The crossing reaches 9 meters wide at the narrowest point and around 18 meters at the entrance. It is approximately 65 meters long. The lanes below the crossing span over 29 meters wide and accommodate additional space for future expansion in case of increased traffic. For example, the Sandsjöbackarising ecoduct has almost the same length and about twice as much width.

The structure vegetation cover at the entrance may hinder ungulate crossing rates.

From the northeastern side, the broken fences are posing a risk to wildlife and drivers. Moreover, the fence on the south side is very visibly bent in a way that would suggest that small animals tried to cross under the fence from the forest towards the highway.

Vegetation on the bridge is diverse, mainly composed of meadow plants and grasses. Small trees and shrubs identified are for example, Prunus spinosa L., and from Crataegus L. family. Many shrubs are covered with thorns, and many of them are hard to identify because of a lack of leafage. It is likely, that many of those plantings are producing fruits to attract animals. The crossing lacks essential features (furniture) such as tree stumps, rock piles, sand mounds, and insect hotels, and no international installation of these elements was detected.

Figure 30 The WCS eastern entrance

Fig

Figure 33 Overpass analysis (map source: Google Earth, modified by me)

ure 31 Vegetation

Figure 32 Broken fencing

The crossing has been used by one-wheeled vehicles. It has a sandy substrate with high porosity, making it highly permeable, although a fraction of clay helps to keep it moist. Various and diverse vegetation growing on the WCS indicates that the substrate holds enough water and supports existing vegetation sufficiently. However, the WCS doesn't seem to be actively maintained. The vegetation grows freely and might be perceived as unsafe by prey species. The represented habitats on the crossing are limited and do not include, for example, ferns and berries which are favoured by moose (Dzięciołowski and Pielowski 1993 see Niedziałkowska et al. 2022). South-facing plants are covered with lichens which are the preferred food source for moose.

Moreover, the acoustic panels do not separate the crossing entrance from the industrial area on the western side (Fig. 33), which might introduce noise disturbance. It is probably less noticeable during the summer months when the vegetation densifies.

The site is accessible for wildlife. Placement of WCS in densely forested areas might cause wildlife to struggle with finding the passage and limit ungulate usage due to the perceived risk of predation (Clevenger and Waltho, 2005 see Denneboom et. al 2021). However, the fencing is supposed to funnel animals toward the structure (Denneboom et. al 2021).

The crossing is only accessible for people by foot or bike, although the western entrance is densely covered with bushes, and it is necessary to go around or squeeze through. Many of the bushes have thorns, thus walking through them proves to be challenging. The eastern entrance is surrounded by hilly and slopy forest which might be problematic for some people to access. Thus, the crossing accessibility to people is hindered.

6. Preconditions for the design proposal

Preconditions for the design proposal include prerequisites regarding moose and site-specific considerations and are summarised in this chapter as a framework that is being used for design development.

This thesis aims to enhance the efficiency of the Älby overpass and improve the connectivity of wildlife habitats in the surrounding which are impacted by urbanization pressures in Nynäshamn municipality. The study case of moose was used as an umbrella species to develop the design proposal.

There are many barriers in Nynäshamn municipality, impacting wildlife to a great extent by habitat fragmentation. Källberga development contributes to habitat fragmentation, by creating an urban sprawl, which might limit east-to-west wildlife connectivity. Such connectivity could be maintained by green corridors which should structurally connect wildlife habitats. The connections should include habitat elements needed by moose within the corridors, accommodating species' needs at all times. Älby overpass is concluded to be the only viable connection between those habitats, and lacks such accommodation, as represented habitat elements are limited and do not address moose's needs and requirements. Moreover, the Sandsjöbacka ecoduct incorporates targeted species' preferred vegetation and extends acoustic screens to reduce disturbances, fostering increased wildlife usage. The overpass's surroundings should be protected from developments, to limit disturbances that could impede the WCS. The analysis identified that the time separation between human and wildlife usage of the WCS allows for feasible co-usage without substantial impact on wildlife crossing rates, thus, human usage is kept.

The main findings regarding moose requirements, Älby overpass and wildlife habitat relationship analysis are listed below.

Forage availability even small improvements are crucial Places to cool down Summer and winter ranges should be connected such connection is at risk due to Källberga development Moose are active mainly during dusk and dawn with diurnal activity patterns

Table 9 Moose main requirements list

Limited habitats represented on the WCS Lack of moose-preferred vegetation Perceived risk of predation due to lush vegetation at the entrance to WCS Lack of furniture Acoustic screens do not limit enough disturbance Fencing needs maintenance Lack of ponds and densely vegetated areas around the WCS The viewing corridor to be preserved Moose have a low usage rate of the WCS There is a time separation between wildlife and human usage

Table 10 List of conclusions from WCS analysis

Cover habitats are within feeding habitats Reproductive habitats are in between feeding habitats Habitats are fragmented by transport infrastructure West-east connection is the most important WCS connects major winter and summer habitats Källberga development needs to be limited WCS surroundings need to be protected Moose vehicle mortality suggests that moose prefer to cross roads in open landscapes

Table 11 List of conclusions from WHR analysis

7. The Design

7.1 Aiding the moose

Aiming at aiding wildlife populations within Nynäshamn municipality *A reconnection of habitats* & *Revision of Älby overpass* design proposals were developed.

On a macro scale, the first proposal presents two actions, the protection of high-importance areas and the establishment of green corridors connecting moose habitats. Additionally, the second proposal focuses on enhancing the WCS to better accommodate moose by addressing their specific needs and requirements. The design proposals are structured in two chapters which share a common vision for the area and the future of the moose population.

Moose-Friendly Crossing: The wildlife crossing is designed to specifically accommodate moose
Resilience to Urbanization Pressure: A wildlife crossing system that promotes responsible use of the crossing by humans to minimize impact on wildlife
Supportive Surrounding Environment: An environment that connects and protects local habitats and ecosystems aligning with the structure's primary aim

Table 12 Vision Objectives

7.2 A reconnection of habitats

The design proposal for habitat connectivity, based on the WHR method, aims to reunite moose habitats and facilitate seasonal movement between summer and winter habitats. Such an approach is meant to benefit species fitness and sustenance. All habitat types: feeding, cover and reproductive are connected structurally, meaning that the connecting corridors are aiming to include all of those habitats within themselves, creating a supportive and complex ecosystem.

The connectivity proposal was based on moose roadkill data (Fig.20), WHR analysis (Fig.25) and nearby crossing analysis (Fig.15). It connects the habitats where moose already cross the transport infrastructure and patches of winter and summer habitats. Moreover, connections are established within open landscapes as those areas appear to be preferred mobility corridors by the species (Fig. 20).

Based on the connectivity proposal (Fig. 34), a wildlife corridor proposal was developed, aiming at structurally connecting habitats. Summer and winter ranges are connected. Moreover, areas designated for special protection were overlayed. The proposal also highlights areas where the capacity of the Källberga development should be limited.

Finally, moose are reliant on wetlands and water bodies as well as on mature and dense forests, where they can seek cover and coolness. The crossing has a possibility of connecting such habitats as specified in the proposal below.

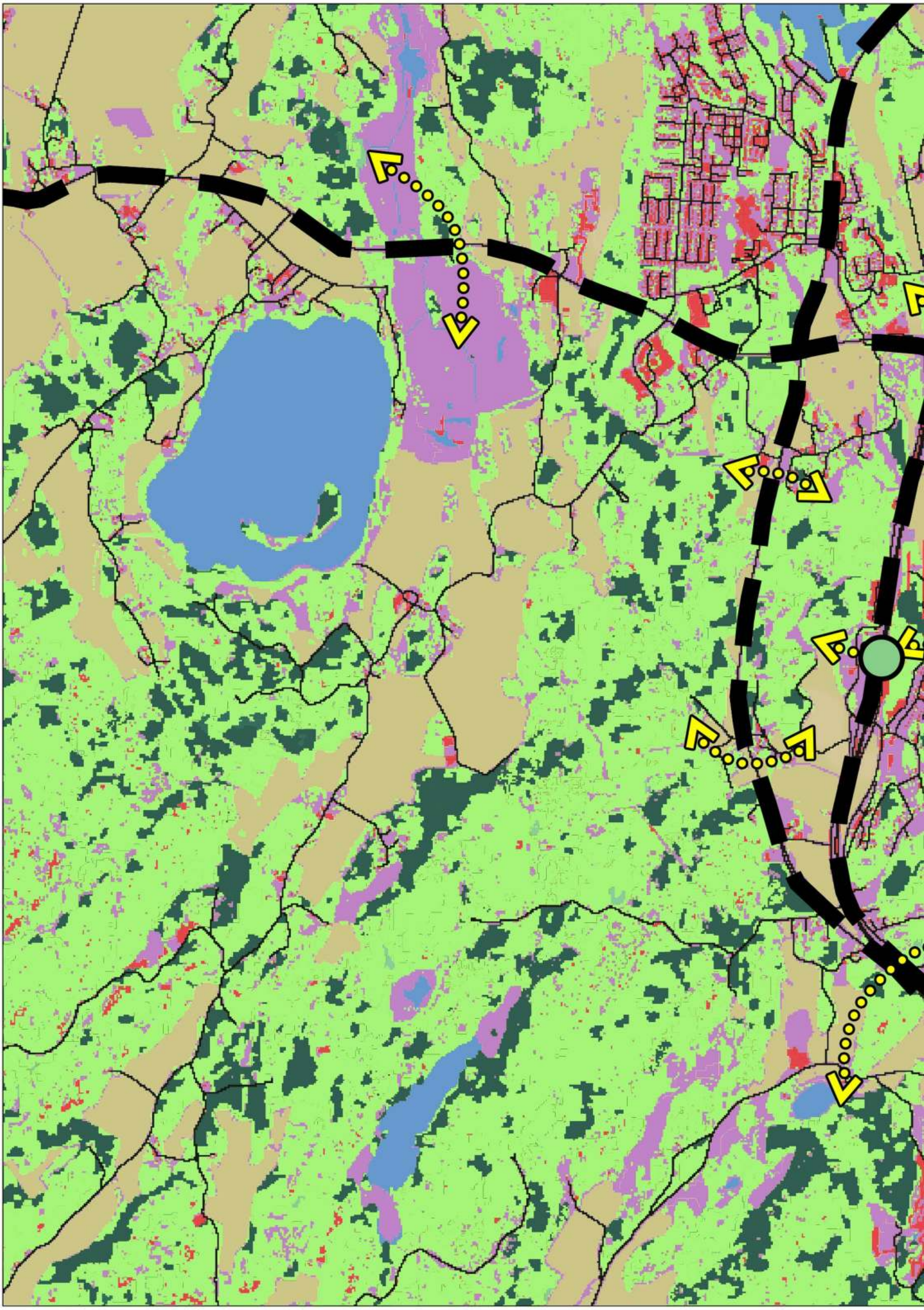
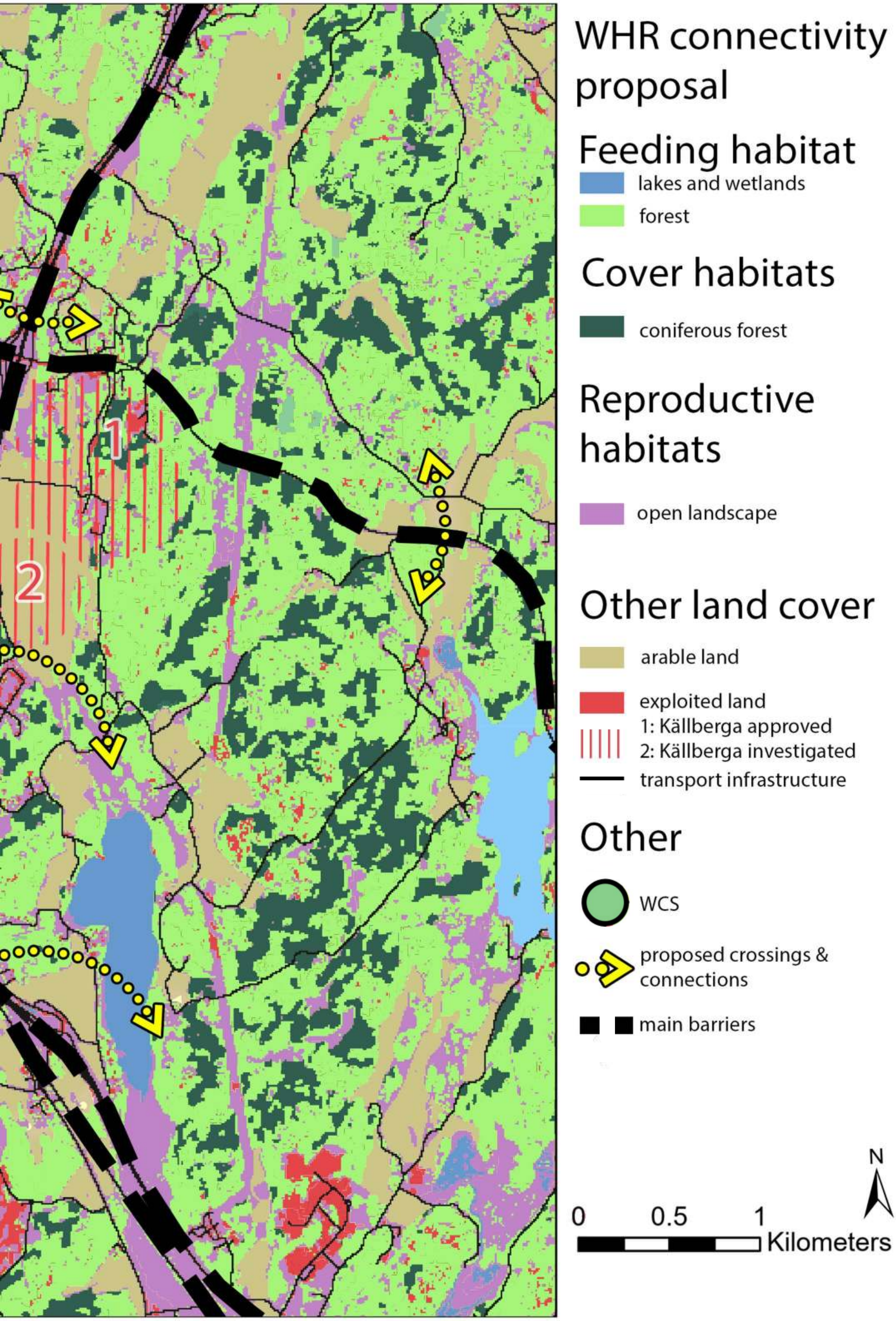


Figure 34 Wildlife Habitat Relationship connectivity proposal (source: The Swedish Environmental Agency, modified


WHR connectivity proposal
Feeding habitat
lakes and wetlands
forest
Cover habitats
coniferous forest
Reproductive habitats
open landscape
Other land cover
arable land
exploited land
1: Källberga approved
2: Källberga investigated
transport infrastructure
Other
WCS
proposed crossings & connections
main barriers
1
2
N
0
0.5
1
Kilometers

by author)

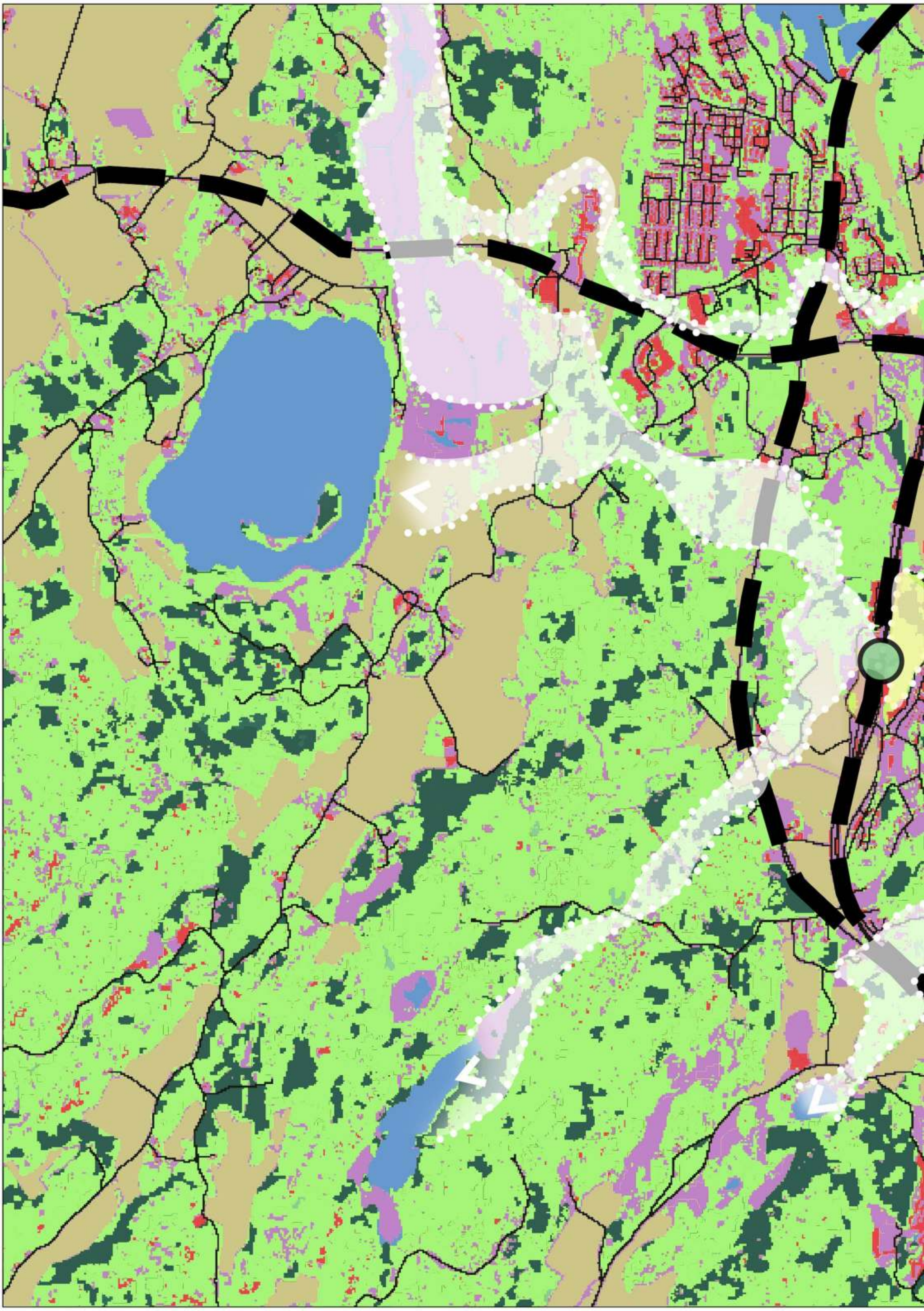
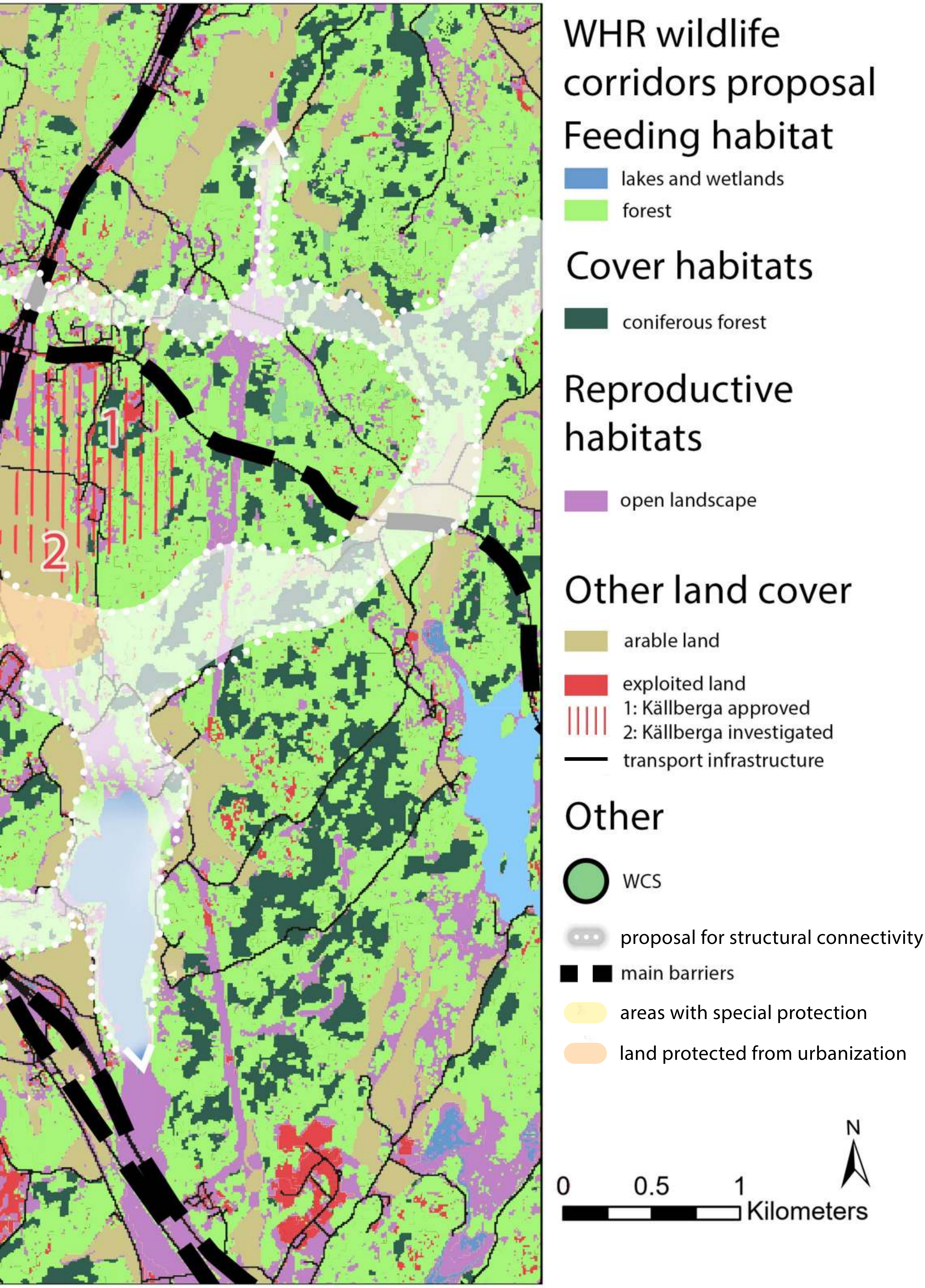


Figure 35 Wildlife Habitat Relationship corridor proposal (source: The Swedish Environmental Agency, modified


WHR wildlife corridors proposal
Feeding habitat
lakes and wetlands
forest
Cover habitats
coniferous forest
Reproductive habitats
open landscape
Other land cover
arable land
exploited land
1: Källberga approved
2: Källberga investigated
transport infrastructure
Other
WCS
proposal for structural connectivity
main barriers
areas with special protection
land protected from urbanization
N
0
0.5
1
Kilometers
1
2

by author)

7.3 Revision of Älby overpass

Plant list:
Ground cover:
Lingonberry *Vaccinium vitis-idaea*
Stone bramble *Rubus saxatilis*
European blueberry *Vaccinium myrtillus*
Herb-paris *Paris quadrifolia*
Baneberry *Actaea spicata*

WCS design is based on researched recommendations and analysis. The design alternations are meant to benefit WCS usage by moose, thus improving the usage by a variety of animals.

The revision of WCS proposes design alternations aimed at aiding the moose. The WCS dimensions and structural characteristics were kept, as they sufficiently support the species. The design alternations are limited within the middle part of the crossing, where vegetation and ground cover are funnelling animals, ensuring viewing corridors and sufficiently accommodating wildlife.

Moose habitats are added to complement the structural habitat connectivity, creating a more efficient connection.

Existing plants

Added plants

Figure 37 WCS proposal (map source: Google Earth, modified by me)

Trees:
Scots pine *Pinus sylvestris*
European aspen *Populus tremula*
Common juniper *Juniper communis*
Willow *Salix sp.*
Rowan *Sorbus aucuparia*
Silver birch *Betula pendula*

Pond:
Lady fern *Athyrium filix-femina*
Male fern *Dryopteris filix-mas*
Ostrich Fern *Matteuccia struthiopteris*

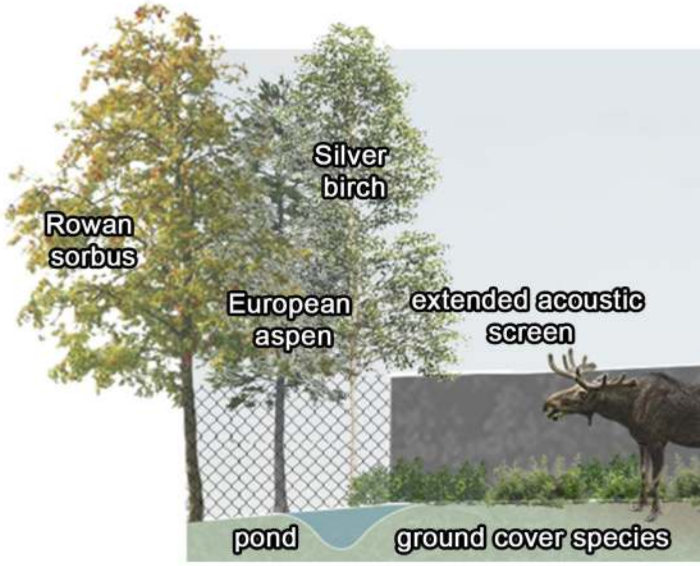


Figure 38 Schematic overpass section, det

The design focuses primarily on the entrances to the crossing, as they were identified as the most problematic. Acoustic screens are extended to limit disturbance and pollution. That created an opportunity for the replacement of the old fencing. The new fence segment is buried in the ground to prevent animals from reaching the road lanes.

Vegetation at the entrances was replaced with ground cover species, to create a better clearance. Tree clusters are placed near newly designed ponds with ferns growing around them.

Furniture was added to the crossing in the form of branch piles and rock piles. Branches are replaced in winter with freshly cut twigs to provide forage all year around.

Information boards were installed at both entrances to provide guidelines on recommended WCS usage and details about the species that utilize it.

Figure 40 Schematic overpass section

tail

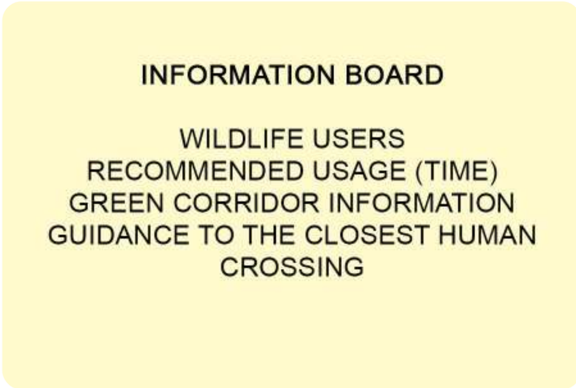


Figure 39 Schematic overpass information board

Figure 41 Inspiration of buried fencing (Mats Lindqvist)

Figure 42 Inspiration of habitat piles (Mats Lindqvist)

8. Discussion

Introduction

This thesis aimed to develop a conceptual plan for the Älby overpass to enhance its efficiency and accommodate the needs of local wildlife populations. Initially focused on the overpass itself, the scope broadened as I gained a deeper understanding of the wildlife dynamics and the study area. Consequently, the thesis seeks to identify the main wildlife habitats and propose a plan for their connectivity in the form of wildlife corridors. Both objectives are centred around the needs and requirements of moose (Alces alces alces), aiming to create habitats that are resistant to the impacts of nearby urban developments. Given that the sustenance of many wildlife species depends on habitat connectivity, the first research question explores how this connectivity can be protected from urbanization and infrastructure developments. The following research question investigates how structural efficiency can be improved while allowing co-use by people on the wildlife crossing, using moose as an umbrella species.

Reflection

The human impact on the natural environment is well-documented in literature and is also evident in this thesis. Humans, as the primary drivers of biodiversity loss on Earth, have created barriers that are impenetrable for animals and pose significant threats to their safety (IPBES 2019). Urban expansion continues to consume increasing amounts of grasslands, agricultural lands, and forests, habitats that are crucial for many species (IPBES 2019). Particularly, urban sprawl, which is rapidly increasing in Europe, consumes more and more wildlife habitats and agricultural fields, creating barriers that fragment and degrade natural environments (Yasin 2020). This trend is also observed in Källberga, where urban development encroaches on wildlife habitats. Habitat fragmentation leaves wildlife subpopulations vulnerable to extinction, as these fragmented connections are vital to their survival. Wildlife crossing structures are widely used to enhance connectivity and mitigate the adverse effects of infrastructure. In the same way, Älby overpass crossings provide safe passage for animals between habitats, while also contributing to human safety. As the construction of such structures becomes more common, the insights and methodologies in the field are continuously advancing. This thesis explores these insights and proposes design improvements to the overpass and the development of habitat connectivity in the form of wildlife corridors.

Results

The design proposal *A reconnection of habitats*, based on the Wildlife Habitat Relationship (WHR) method, aims to reconnect moose habitats in Nynäshamn municipality. By utilizing moose roadkill data (Fig. 20) and WHR analysis (Fig. 25 and 34), the proposal ensures that the corridors align with natural moose movement patterns, enhancing connectivity between their summer and winter habitats. These corridors integrate feeding, cover, and reproductive areas, contributing to a more resilient ecosystem. It appears that moose prefer to cross transport infrastructure in open landscapes (Fig. 20), such as fields and meadows, so the wildlife corridors follow this pattern. This preference is theorized to align with the species' comfort in open areas (Smith et al., 2015), as confining structures or landscape elements can undermine their confidence (Ruediger and DiGiorgio, 2007; see Denneboom et al., 2021). However, moose might simply choose to cross transport infrastructure where fencing ends or is interrupted, such as at highway exits, which could undermine the previous explanation. However, not all crossing locations can be explained by the second hypothesis alone. Furthermore, restricting development in certain parts of Källberga helps mitigate the impact of urban sprawl, which has the potential to fragment the habitats by creating a barrier effect, ensuring the corridors remain functional.

Revision of the Älby overpass proposal is crucial for improving moose movement across fragmented habitats. Analysis of WCS usage and roadkill data underscores the need for enhancements targeting moose, such as incorporating species-preferred vegetation and extending acoustic screens to mitigate light and noise disturbances that wildlife typically avoids.

The data also validates using moose as an umbrella species, revealing a high incidence of moose roadkill despite their limited use of existing crossings (on page 512). By addressing these specific needs, the proposed design boosts the effectiveness of WCS and supports the long-term viability of moose populations. Additionally, the Älby overpass is essential for habitat connectivity, as no other nearby crossing sufficiently supports species mobility impaired by Road 73.

The analysis of human and wildlife usage patterns reveals a natural separation in time, with human activity peaking during midday and wildlife primarily using the crossing at night (51on page 513)5.5. This temporal gap supports the sustainable co-usage of the crossing, minimizing conflicts and ensuring its effectiveness for both wildlife and humans. The data suggest that the time separation is sufficient to allow for shared use without significantly impacting wildlife crossing rates. Similar findings were made by Knufinke et al. (2019), where human and wildlife usage followed a similar pattern. In that study, time separation did not significantly impact wildlife usage rates, indicating that co-use by wildlife and people is possible without additional design alterations if human use is restricted to particular times of the day (Knufinke et al. 2019).

Additionally, the design modifications are specifically adapted to meet moose habitat requirements, which are likely to increase the species' use of the overpass, as demonstrated by the Sandsjöbacka ecoduct (Swedish Transport Administration 2020). These adjustments also benefit other species, as the moose serves as an umbrella species.

This study demonstrates that strategic design improvements focused on reconnecting habitats, and protecting and enhancing overpass functionality should be prioritized to support moose populations in Nynäshamn. By specifically addressing moose needs and mitigating the effects of urbanization, the proposed designs provide a practical solution for maintaining biodiversity and ensuring the long-term survival of local wildlife.

Landscape architecture and wildlife projects

Greco (n.d.) advocates for the use of the Wildlife Habitat Relationships (WHR) method, which can ensure that greenways and landscapes are designed to meet the ecological and habitat requirements of wildlife species. For these considerations to be effective, they must be intentionally and carefully integrated into the design process (Greco n.d.). Greco argues that the lack of implementation of such a model in the design process likely results in the failure to effectively accommodate targeted wildlife species in greenways or landscapes. Furthermore, this method is at the fringe of the landscape architecture profession and is rarely incorporated into field textbooks, although it is included in literature aimed at wildlife habitat analysis (Greco n.d.). Therefore, Greco (n.d.) argues for its implementation in landscape architecture curricula, as it has been demonstrated that students can effectively learn and apply the model in wildlife corridor design.

The WHR method could be more broadly incorporated into the field of landscape architecture, as environmental and sustainable perspectives are becoming increasingly relevant. Such integration would improve professional practice by providing designers with ecologically informed infrastructure guidelines.

Limitations and future research

The student projects presented by Greco (n.d.) use a WHR method based on software provided by the state of California, meaning that sourcing information about species requirements was eased. In my thesis this proved to be a difficulty and consumed much of my resources and time, thus the analysis of the suitability of habitats was omitted. If included, such analysis evaluates habitat suitability on a scale from high (1.0) to unsuitable (0), while low and medium are in between. Depending on the chosen metrics, which combine the scores, a rating of habitats is created. However, the results are believed to be sufficient as moose are flexible species regarding their habitat preference and can adapt, as long as their environments provide sufficient opportunities for foraging and cover (Bjørneraas et al., 2011 see Janík et al. 2021). Therefore, all the habitats were assumed to be suitable, based on the species' adaptability. A limitation of this study is that habitat connectivity was analysed within the home range of moose, excluding species migration. However, the analysis revealed many species habitats, with summer ranges bordering winter ranges. Therefore, migration may not be necessary for the individuals living in the area (Borowik et al. 2020).

Another limiting factor was the study's time frame, which analyses the developments until 2050. Since wildlife crossing structures are designed for longer periods, the future effectiveness of the crossing remains uncertain. Moreover, the maintenance plan along with ongoing monitoring, are integral to the long-term success of Wildlife Crossing Structures (WCS), as they ensure the structures' continued functionality and ecological effectiveness, which was omitted in this thesis due to time constraints. While these considerations could add valuable insights into the topic, they do not appear to be necessary to enhance the current wildlife situation in the area.

Additionally, my understanding of urbanization in Nynäshamn is limited, and the complexity of wildlife protection from its effects is likely to be more complicated than presented in this thesis. While urban sprawl in the municipality appears prevalent, it does not necessarily result in further habitat fragmentation. Low-density housing can be accessed by animals and is frequently visited by various ungulates and large mammal species, often not constituting a barrier (Ciach & Fröhlich 2019). Conversely, such developments do occupy land previously serving as wildlife habitats and have the potential to fragment the landscape (Yasin 2020).

The thesis uses the concept of an “umbrella species” to establish general criteria for a well-functioning wildlife crossing structure. The moose (*Alces alces alces*) was chosen due to its high habitat requirements, making it a suitable species for meeting the needs of other animals (Seiler et al. 2015). However, this approach has limitations and may not apply to all species in the area, particularly predators like wolves and bears, which tend to have conflicting preferences regarding wildlife crossing structures (Denneboom et al. 2021). Consequently, the design proposal is meant to benefit some species, potentially reducing usage rates for others. Nevertheless, data on crossing users indicates that carnivores are not frequent users, and moose are not well adapted to the current crossing. Thus, choosing moose as an umbrella species is justified by the needs of the local wildlife.

Conclusions

Design modifications of the overpass and wildlife corridor proposal could enhance wildlife livelihood and populations. These benefits could be delivered without negatively impacting human usage of the structure. Therefore, the thesis does not propose completely prohibiting human use but rather promotes responsible usage with time separation, allowing both wildlife and people to benefit from the crossing's connectivity. Additionally, the thesis does not aim to entirely abolish urbanization plans, such as those for Källberga, as these developments are important from a human perspective. Instead, the thesis proposes limiting the extent of development to protect environments and habitats, thereby sustaining wildlife populations and their necessary connectivity. However, more research is needed regarding human usage impacts on wildlife, to develop more concrete recommendations and better understanding. The same applies to research regarding the structural qualities of WCSs, as many recommendations from various sources contradict with each other, while some of them need further studies to develop scientific consensus. Moreover, the WHR method could be applied with a broader array of variables, creating a more in-depth study of species habitat relationships. Finally, while not explicitly addressed in the thesis, continued monitoring and adaptation of WCSs over time are still crucial for maintaining their effectiveness and supporting wildlife populations in the face of ongoing urbanization and environmental changes.

References

Archus Development (n.d.a). Källberga is an accommodation close to nature with a focus on social and ecological sustainability. https://static1.squarespace.com/static/5cc0677f4d546e700a02a721/t/5cc311aabce2130001a1e978/1556287967267/K%C3%A4llberga+gestaltningsprogram.pdf [25.04.2024]

Archus Development (n.d.b). Welcome to Källberga. https://www.kallberga.se/ [23.04.2024]

Archus Development (n.d.c). Källberga The vision of a new district in the country.https://static1.squarespace.com/static/5cc0677f4d546e700a02a721/t/5cc6d3ab971a181ca106836c/1556534206034/Visionsbok.pdf [25.04.2024]

Borowik, T., Ratkiewicz, M., Maślanko, W., Duda, N., & Kowalczyk, R., (2020). The level of habitat patchiness influences the movement strategy of moose in Eastern Poland. *PLoS One*, 15(3), p.e0230521. Available at: https://doi.org/10.1371/journal.pone.0230521

C., Seiler, A., Chrétien, L., Guinard, E., Hlaváč, V., Moulherat, S., Fernández, L.M., Georgiadis, L., Mot, R., Reck, H., Sangwine, T., Sjolund, A., Trocmé, M., Hahn, E., Bekker, H., Bíl, M., Böttcher, M., O'Malley, V., Autret, Y., & van der Grift, E. (Eds.)., (2023). IENE Biodiversity and Infrastructure. A handbook for action. https://www.biodiversityinfrastructure.org/

Ciach, M. & Fröhlich, A., (2019). Ungulates in the city: light pollution and open habitats predict the probability of roe deer occurring in an urban environment. Urban Ecosystems, 22, pp. 1021-1033. DOI: 10.1007/s11252-019-00840-2.

Corbisier, C. (2023). Living With Noise. Public Roads - July/August 2003. Issue No: Vol. 67 No. 1. https://highways.dot.gov/public-roads/julyaugust-

2003/living-noise#:~:text=The%20(A)%20refers%20to%20a,50%20feet [22.04.2024]

Cooperrider, A. Y. (1986). Developing an interdisciplinary approach to conservation. *Journal of Wildlife Management*, 50(3), 409-414.

CORLATTI, L., HACKLÄNDER, K. and FREY-ROOS, F., (2009). Ability of Wildlife Overpasses to Provide Connectivity and Prevent Genetic Isolation. Conservation Biology, 23: 548-556. https://doi.org/10.1111/j.1523-1739.2008.01162.x

Denneboom, D., Bar-Massada, A., Shwartz, A., (2021). Factors affecting usage of crossing structures by wildlife – A systematic review and meta-analysis. Human and Biodiversity Research Lab, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa 32000, Israel b Faculty of Natural Sciences, University of Haifa, Kiryat Tivon 36006, Israel.

Dorsey, B., Olsson, M. and Rew, L.J., (2015). 'Ecological Effects of Railways on Wildlife', in van der Ree, R., Smith, D.J. and Grilo, C. (eds.) Handbook of Road Ecology. Wiley Blackwell, pp. 262-273. Available at: https://doi.org/10.1002/9781118568170.ch26

Dou, H., Jiang, G., & Stott, P. (2013). Evaluating the effectiveness of wildlife crossings in reducing animal-vehicle collisions. *Transportation Research Part D: Transport and Environment*, 17(8), 605-614.

Ekologi Gruppen (2016). Natural value inventory of wetlands and mountain pine forest at Källberga, Nynäshamn municipality. https://nynashamn.se/download/18.51ec72a6175022eb0cb16c6/1602147251877/Naturv%C3%A4rdesinventering%20av%20v%C3%A5tmarker%20och%20%C3%A5sbarrsskog.pdf [25.04.2024]

Forman, R. T. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29, 207-231.

Gibson, R. B., (2006). Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic, and ecological considerations in significant decision-making. Journal of Environmental Assessment Policy and Management, 8(3), 259–280

Greco, M. (n.d.). *The Wildlife Habitat Relationships (WHR) Method: A Comprehensive Guide*. Center for Environmental Law and Policy. Available at: https://thecela.org/wp-content/uploads/GRECO.pdf (1.08.2024)

Håkansson, E., Olsson, M., Wahlman, H., EnviroPlanning AB., (2022). Viltutredning_Stockholms_län_ver2. TRV 2022/8152

Helldin, J. O., Elfström, M., Håkansson, E., Olsson, M., & Seiler, A., (2023). Fauna passages by roads and railways. *Fauna & Flora*, 118(4), 2–9

Holmes, S. M., Cromsigt, J. P. G. M., Danell, K., Ericsson, G., Singh, N. J., & Widemo, F., (2021). Declining recruitment and mass of Swedish moose calves linked to hot, dry springs and snowy winters. *Department of Wildlife, Fish and Environmental Studies, Swedish University of Agricultural Sciences, Umeå 90183 Sweden

IPBES, (2019). Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In Brondízio, E. S., Settele, J., Díaz, S., & Ngo, H. T. (Eds.). IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1
Iterio (2018). EIA for detailed plan Vidbynäs 1:3 etc. Housing in Källberga, Nynäshamn municipality. https://nynashamn.se/download/18.12c8ca0d174e44c093d8165/1602061272386/Milj%C3%B6konsekvensbeskrivning%20dp%20Vidbyn%C3%A4s%201_3_bost%C3%A4der%20i%20K%C3%A4lllberga_%20sluthandling_20180307.pdf [23.04.2024].

Janík, T., Peters, W., Šálek, M., Romportl, D., Jirků, M., Engleder, T., Ernst, M., Neudert, J., & Heurich, M., (2021). The declining occurrence of moose (*Alces alces*) at the southernmost edge of its range raises conservation concerns. *Ecology and Evolution*, 11(10), 5468–5483. https://doi.org/10.1002/ece3.7441

Khan, J., Hildingsson, R., & Garting, L., (2020). Sustainable Welfare in Swedish Cities: Challenges of Eco-Social Integration in Urban Sustainability Governance. Sustainability, 12(1), 383. https://doi.org/10.3390/su12010383

Knufinke, J.F., Helldin, J.O., Bhardwaj, M., Olsson, M., (2019). Temporal patterns of humans and ungulates at bridges. TRIEKOL – Applied Road and Rail Ecology.

Korytarze ekologiczne (2021). Moose on the S6 expressway - a hair's breadth from tragedy due to disastrous crossings built by GDDKiA. https://korytarze.pl/aktualnosci/22-losie-na-drodze-ekspresowej-s6-o-wlos-od-tragedii-przez-fatalne-przejscia-wybudowane-przez-gddkia [25.04.2024].

Krausman, P.R. and Morrison, M.L., (2016). Another plea for standard terminology. Journal of Wildlife Management, 80(7), pp.1143-1144. https://doi.org/10.1002/jwmg.21121

Lodnert, D., (2021). Evaluating the behavioural response of moose (Alces alces) to acoustic stimuli. Master's thesis. Swedish University of Agricultural Sciences, SLU

Malmsten, J. (2014). Evaluating the design and effectiveness of wildlife crossings in Sweden. *Journal of Transportation Engineering*, 140(3), 04014007.

Mirzoev, T., Tull, K. I., Winn, N., Mir, G., King, N. V., Wright, J. M., & Gong, Y. Y., (2022). Systematic review of the role of social inclusion within sustainable urban developments. International Journal of Sustainable Development & World Ecology, 29(1), 3-17. https://doi.org/10.1080/13504509.2021.1918793

Morgan, D.L., 2007. Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research*, 1(1), pp.48-76.

Murray, D. L., & Lenarz, M. S. (2006). Large mammal ecology in boreal forests: Implications for wildlife corridors. *Journal of Applied Ecology*, 43(2), 349-358.

National Wildlife Accident Council (n.d.). Number of wildlife accidents handled. https://www.viltolycka.se/start/ [01.03.2024]

Niedziałkowska, M., et al., (2022). Moose Alces alces (Linnaeus, 1758). In: Corlatti, L., Zachos, F.E. (eds), *Terrestrial Cetartiodactyla*. Handbook of the Mammals of Europe. Springer, Cham. https://doi.org/10.1007/978-3-030-24475-0_23

Nynäshamn municipality (2024a). Nature conservation. https://nynashamn.se/service/boende--miljo/hallbarhet-miljo--och-naturvard/naturvard [25.04.2024]

Nynäshamn municipality (2024b). Game conservation and protective hunting. https://nynashamn.se/service/boende--miljo/hallbarhet-miljo--och-naturvard/viltvard-och-skyddsjakt [21.05.2024]

Nynäshamn municipality (2024c). Comprehensive plan Consultation documents. https://nynashamn.se/tillvaxt/stadsplanering--byggnation/oversiktlig-planering/samradshandlingar [24.05.2024]

Olsson, M., Seiler, A., Willebrand, S., & Wahlman, H., (2019). Viltolyckskartor och Barriärkartor – Handledning för tillämpning i åtgärdsarbete. Publikationsnummer 2019:178. ISBN 978-91-7725-530-7
Oxford English Dictionary. "Sustainability (n.), sense 2.b.", (2023). Accessed May 15, 2024. https://doi.org/10.1093/OED/1042593202

Paton, D. G., S. Ciuti, M. Quinn, and M. S. Boyce., (2017). Hunting exacerbates the response to human disturbance in large herbivores while migrating through a road network. Ecosphere 8(6):e01841. 10.1002/ecs2.1841

Pecorella, I. & Ferretti, Francesco & Sforzi, Andrea & Macchi, Elisabetta., (2016). Effects of culling on vigilance behaviour and endogenous stress response of female fallow deer. Wildlife Research. 43. 10.1071/WR15118.
Reimoser, F. and Nopp-Mayr, U., (2024). 'Ecology, Diversity, Conservation and Management of Ungulates', Diversity, 16(3), p. 182. Available at: https://doi.org/10.3390/d16030182

Priya, A. (2021). Case Study Methodology of Qualitative Research: Key Attributes and Navigating the Conundrums in Its Application. Sociological Bulletin, 70(1), 94-110. https://doi.org/10.1177/0038022920970318

Ree, R. van der, Smith, D. J., & Grift, E. van der (2011). The ecological effectiveness of road mitigation measures: A review of past and future research. *Ecology and Society*, 16(2), 48.

Rezvani, S., Nopp-Mayr, U., & Silva, P. (2024). Habitat connectivity for large mammals in the face of urbanization: A European perspective. *Landscape and Urban Planning*, 227, 104573.

Rosell, C., Seiler, A., Chrétien, L., Guinard, E., Hlaváč, V., Moulherat, S., Fernández, L.M., Georgiadis, L., Mot, R., Reck, H., Sangwine, T., Sjolund, A., Trocmé, M., Hahn, E., Bekker, H., Bíl, M., Böttcher, M., O'Malley, V., Autret, Y., & van der Grift, E. (Eds.)., (2023). IENE Biodiversity and infrastructure. A handbook for action. 5. Solutions to mitigate impacts and benefit nature https://www.biodiversityinfrastructure.org/

Rosendahl, H., Ekvall, J., Ståhl, P., Fintling Rue, C., and Miljö- och samhällsbyggnadsförvaltningen, (2012) Comprehensive Plan for Nynäshamn Municipality. Adopted by the municipal council 17 October 2012 (Kf §207)

Ruediger, B., & DiGiorgio, M. (2007). Corridor Ecology: The science and practice of linking landscapes for biodiversity conservation. *Island Press.*

Rytwinski, T., & Fahrig, L. (2015). Road mortality and the mitigation of its effects on wildlife populations. *Conservation Biology*, 29(2), 330-339.

SCB, The Statistics Authority (2024). Population and Population Changes - Quarter 4, 2023. https://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/folkmangd-och-befolkningsforandringar---manad-kvartal-och-halvar/folkmangd-och-befolkningsforandringar---kvartal-4-2023/ [23.04.2024]

Seiler, A., Helldin, J.O., (2006). Mortality in wildlife due to transportation. Swedish University of Agricultural Sciences, Dept. of Conservation Biology, Grimsö Wildlife Research Station, SE-73091 Riddarhyttan, Sweden

Seiler, A., Olsson, M., & Lindqvist, M., (2015). Analys av infrastrukturens permeabilitet för klövdjur - en metodrapport. CBM:s skriftserie, 88. ISSN 1403-6568. ISBN 978-91-89232-99-0

Silva, C. & Ma, J., (2021) "A Sustainable Urban Sprawl? The Environmental Values of Suburban Interstitial Spaces of Santiago de Chile." disP - The Planning Review, 57(3), pp. 50-67. DOI: 10.1080/02513625.2021.2026667. Available at: https://doi.org/10.1080/02513625.2021.2026667

Smith, D.J., van der Ree, R. & Rosell, C., (2015). WILDLIFE CROSSING STRUCTURES: AN EFFECTIVE STRATEGY TO RESTORE OR MAINTAIN WILDLIFE CONNECTIVITY ACROSS ROADS. Handbook of Road Ecology, First Edition.

Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J., (2014). Land sharing vs. land sparing: does the compact city reconcile urban development and biodiversity conservation? Journal of Applied Ecology, 51, 1378–1386
Swedish Transport Administration (2018). Ecoduct and fauna measures break the barrier effect at Sandsjöbacka. https://bransch.trafikverket.se/contentassets/83e2ec15e7b24cfcb8be6dd54918ef98/201800822_folder-a4_vag-e6-faunapassage.pdf [19.04.2024]

Swedish Transport Administration (2020). E6, fauna passages at Sandsjöbacka. https://bransch.trafikverket.se/for-dig-i-branschen/miljo---for-dig-i-branschen/natur-kultur-och-landskap/viltolyckor-barriarer-och-sakra-passager-for-djur/e6-faunapassager-vid-sandsjobacka/ [19.04.2024]

Swedish Transport Administration (n.d.). NVDB on map. https://nvdbpakarta.trafikverket.se/map [15.04.2024]

Telsaç, C. & Kandeğer, B., (2022). SUSTAINABLE URBANIZATION. 6th INTERNATIONAL NEW YORK CONFERENCE ON

Trafikverket, (2015). Riktlinje landskap. TDOK 2015:0323. Version 2019-03-15

Triekol (n.d.a) https://triekol.se/ [22.04.2024]

Triekol b (n.d.b) Over- and underpasses for larger wildlife TRIEKOL III
The Swedish Environmental Protection Agency (2023). National Land Cover Database (NMD). https://www.naturvardsverket.se/en/services-and-permits/maps-and-map-services/national-land-cover-database/ [18.05.2024]

van der Ree, R. & van der Grift, E.A., (2015). RECREATIONAL CO-USE OF WILDLIFE CROSSING STRUCTURES. Handbook of Road Ecology, First Edition

van der Ree, R., Jaeger, J.A.G., van der Grift, Edgar A., Clevenger, A.P., (2011). Effects of Roads and Traffic on Wildlife Populations and Landscape Function: Road Ecology is Moving toward Larger Scales. Ecology and Society

Wikipedia contributor (2023), 'Riksväg 73', Wikipedia. https://sv.wikipedia.org/wiki/Riksv%C3%A4g_73#cite_note-5 [21.05.2024]

Wikipedia contributors. (2024). European route E6. In Wikipedia, The Free Encyclopedia.https://en.wikipedia.org/w/index.php?title=European_route_E6&oldid=1223720940 [19.04.2024]

Yasin, M., (2020). Is urban sprawl a threat to sustainable development? A review of characteristics and consequences. Malaysian Journal of Society and Space. 16. 56-68. 10.17576/geo-2020-1604-05

Yellowstone to Yukon Conservation Initiative (2016). How do wildlife know to use animal bridges and crossings? https://y2y.net/blog/how-do-wildlife-know-to-use-animal-bridges/#:~:text=There%20is%20a%20%E2%80%9Clearning%20curve%E2%80%9D%20for%20animals%20to,before%20they%20feel%20secure%20using%20newly%20built%20crossings [25.04.2024].

Table of Figures

Appendix - maps

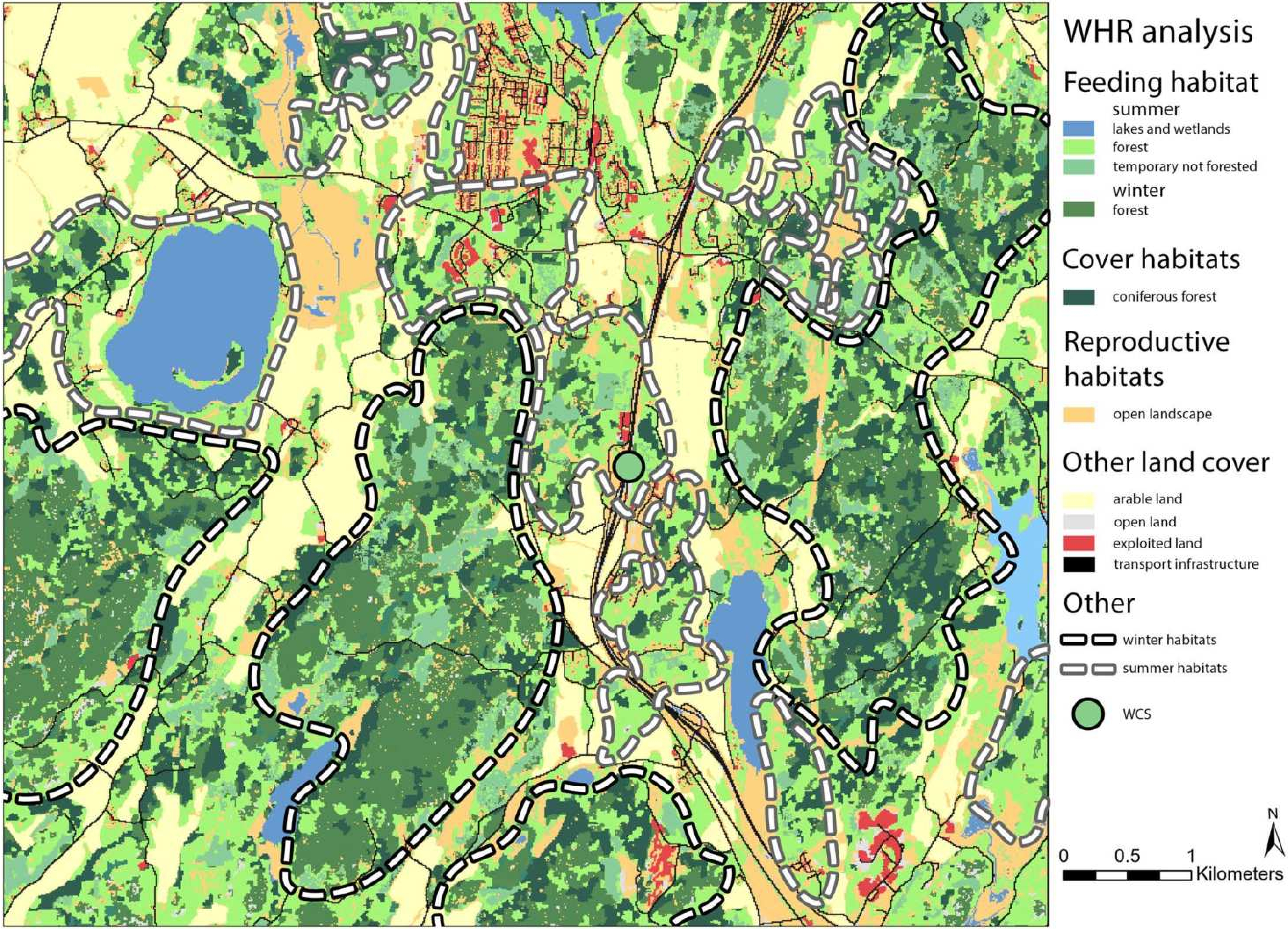


Figure 25 Wildlife Habitat Relationship analysis (source: The Swedish Environmental Protection Agency, modified by author)

5.7 Overpass analysis - identification of design flaws and inefficiencies

Figure 26 Densely forested slope

Figure 27 Sparsely forested hilltop

Figure 28 Path towards the overpass

The immediate surroundings of the crossing are currently undeveloped, though some plans suggest that this may change soon. While the western entrance, which includes protection measures, and the hilly eastern entrance are unlikely to see development, the planned Kallberga development poses a potential risk to both the wildlife and the functionality of the overpass.

The map highlights the proximity of Lidatorp to the crossing and the path that connects them (Fig. X). The forested hill (Fig. X) is denser along the slope but becomes sparser toward the top (Fig. X).

Land cover

sparse forest on the hill top

dens forest on the slope

path leading to the overpass

fencing

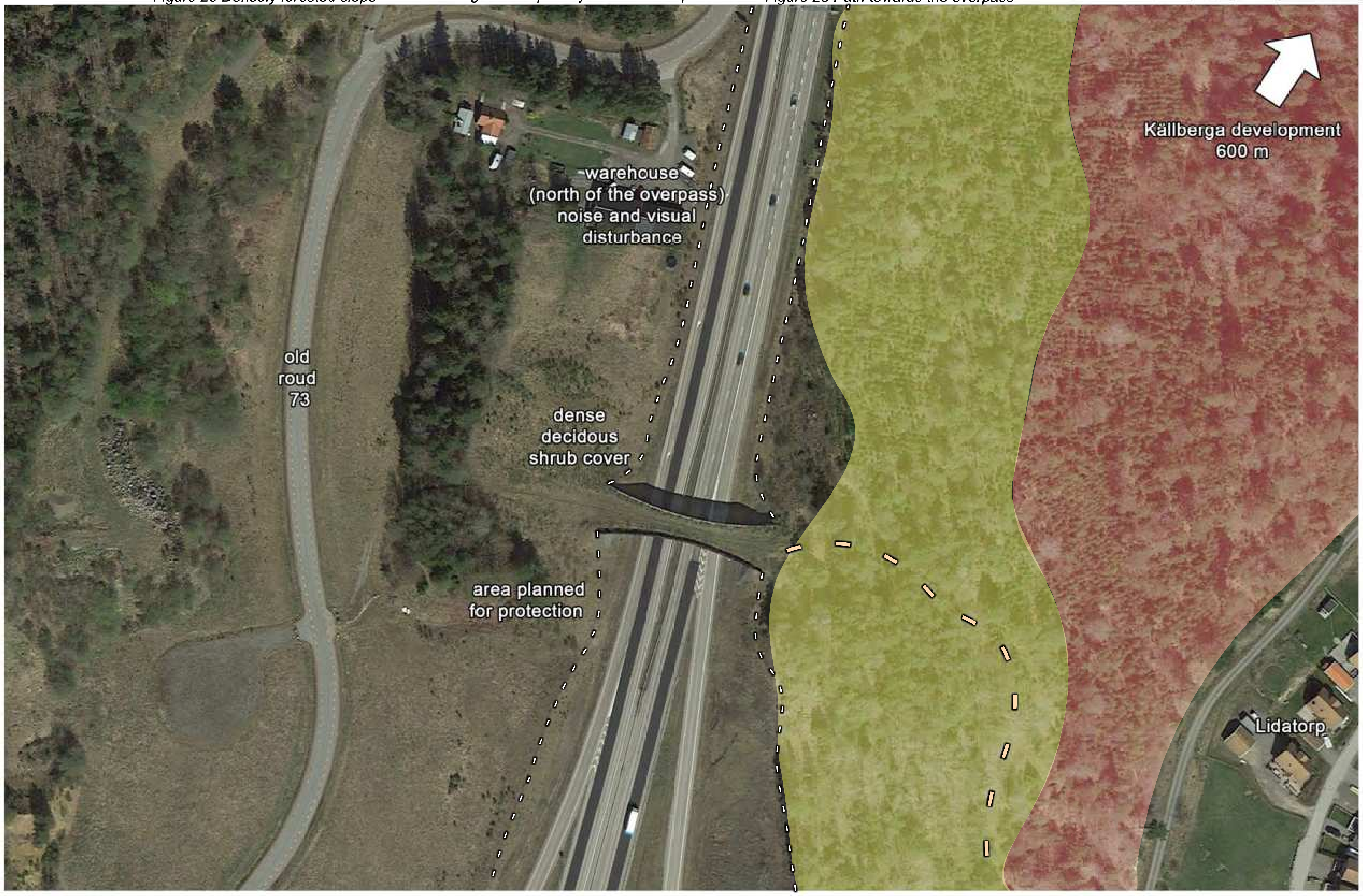


Figure 29 Overpass surroundings analysis (map source: Google Earth, modified by author)

The crossing reaches 9 meters wide at the narrowest point and around 18 meters at the entrance. It is approximately 65 meters long. The lanes below the crossing span over 29 meters wide and accommodate additional space for future expansion in case of increased traffic. For example, the Sandsjöbackarising ecoduct has almost the same length and about twice as much width.

The structure vegetation cover at the entrance may hinder ungulate crossing rates.

From the northeastern side, the broken fences are posing a risk to wildlife and drivers. Moreover, the fence on the south side is very visibly bent in a way that would suggest that small animals tried to cross under the fence from the forest towards the highway.

Vegetation on the bridge is diverse, mainly composed of meadow plants and grasses. Small trees and shrubs identified are for example, Prunus spinosa L., and from Crataegus L. family. Many shrubs are covered with thorns, and many of them are hard to identify because of a lack of leafage. It is likely, that many of those plantings are producing fruits to attract animals. The crossing lacks essential features (furniture) such as tree stumps, rock piles, sand mounds, and insect hotels, and no international installation of these elements was detected.

Figure 30 The WCS eastern entrance

Figure 31 Vegetation

Figure 32 Broken fencing

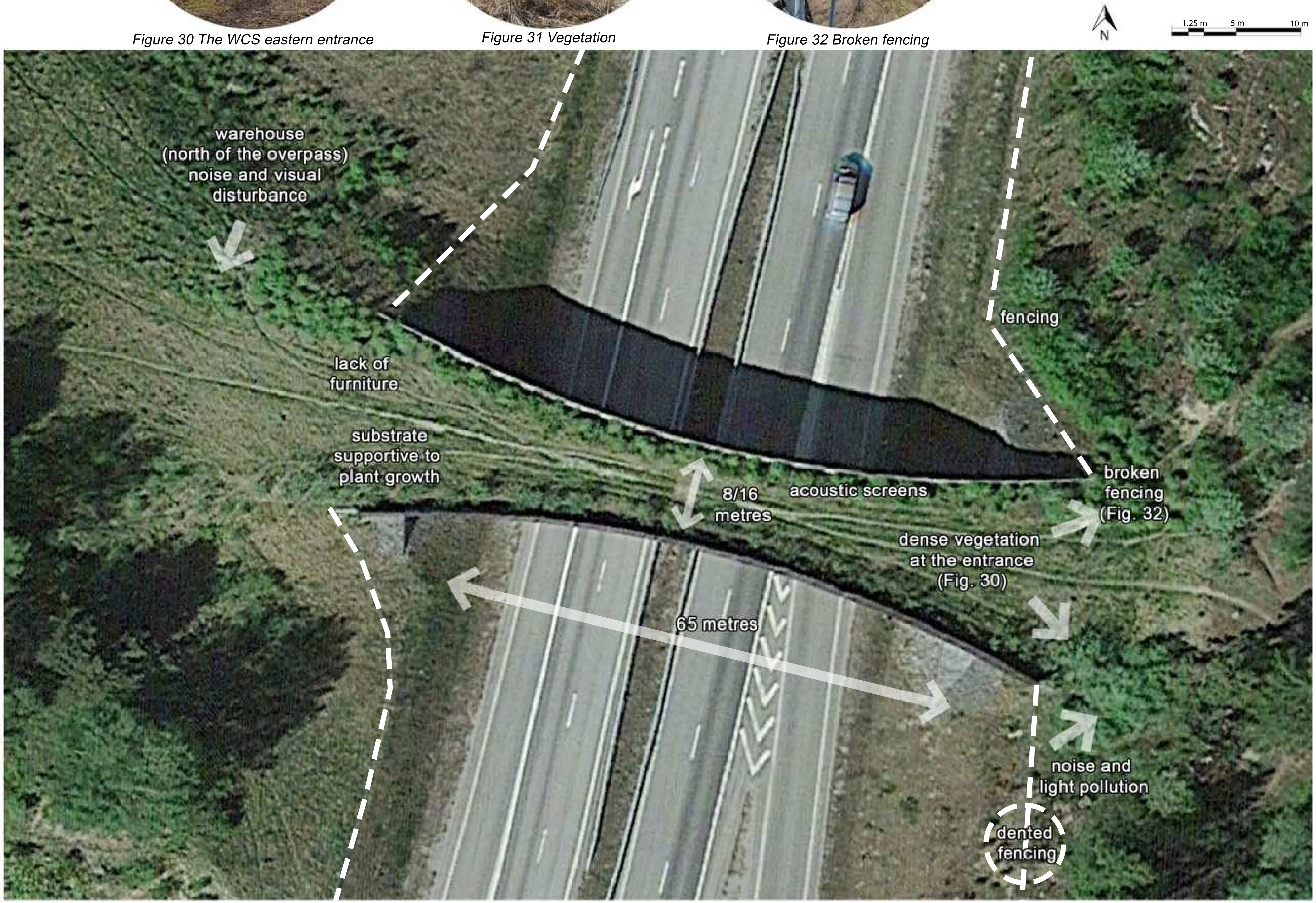


Figure 33 Overpass analysis (map source: Google Earth, modified by me)

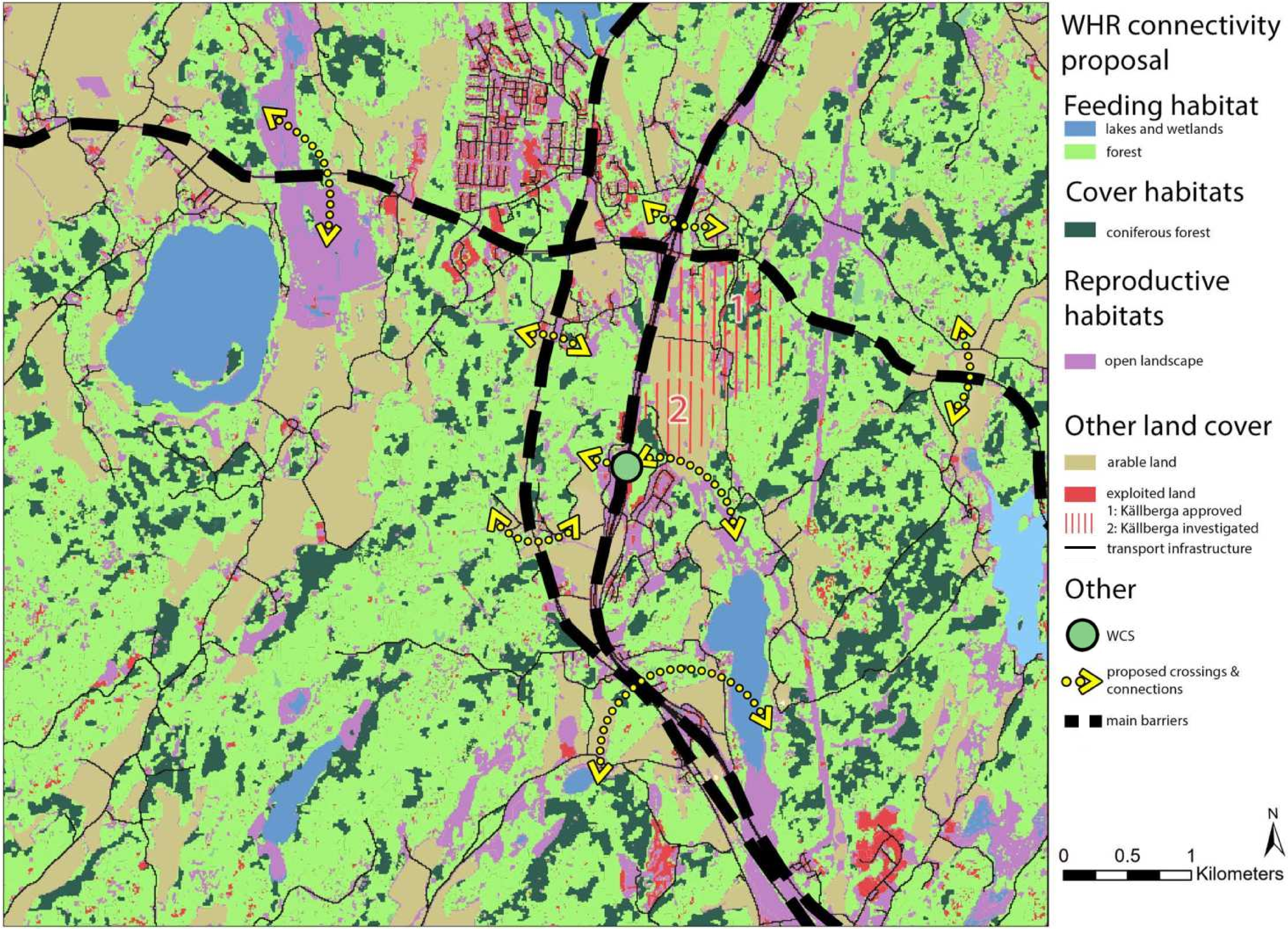


Figure 34 Wildlife Habitat Relationship connectivity proposal (source: The Swedish Environmental Agency, modified by author)

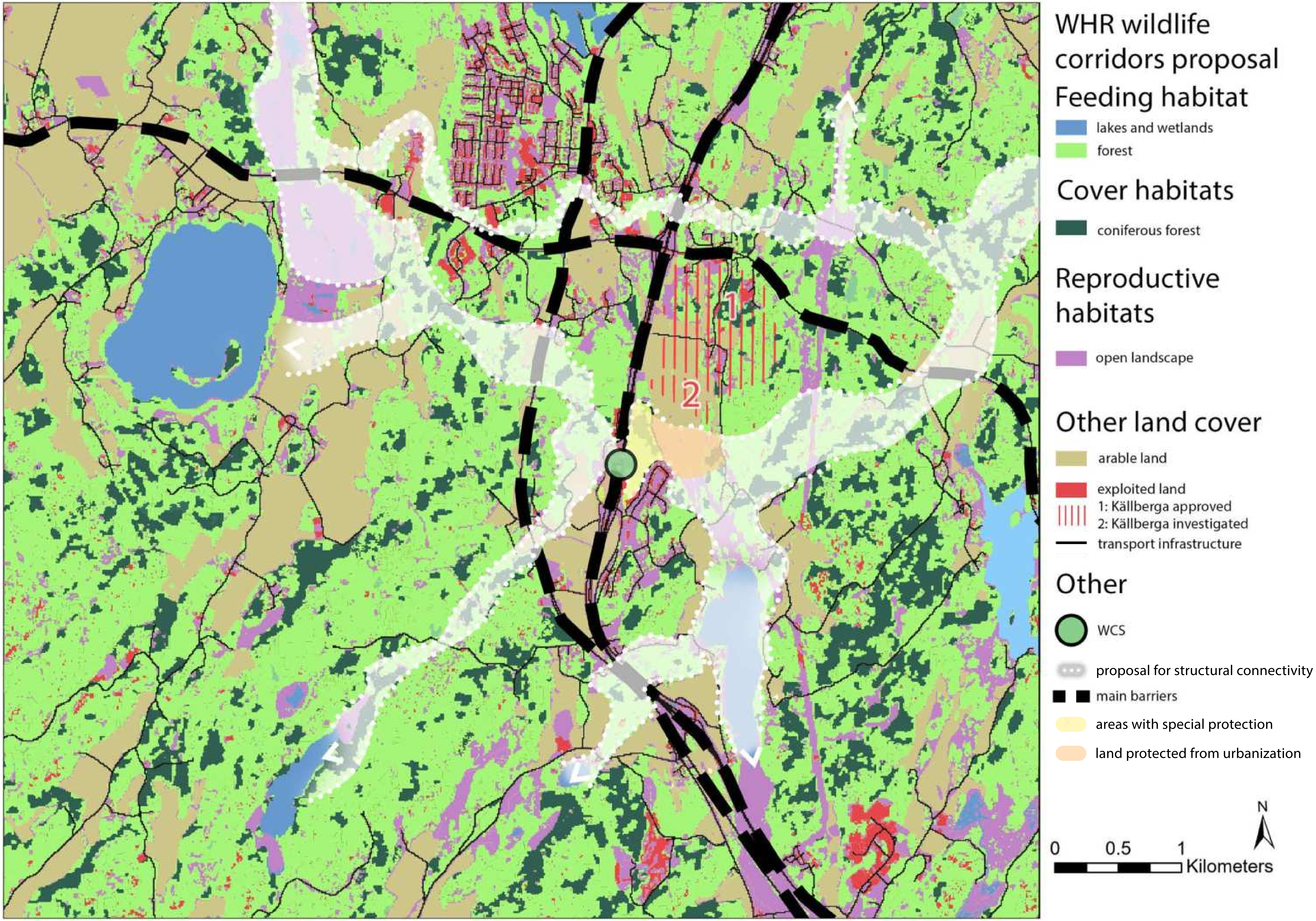


Figure 36 Wildlife Habitat Relationship corridor proposal (source: The Swedish Environmental Agency, modified by author)

7.3 Revision of Älby overpass

Plant list:

Ground cover:
Lingonberry *Vaccinium vitis-idaea*
Stone bramble *Rubus saxatilis*
European blueberry *Vaccinium myrtillus*
Herb-paris *Paris quadrifolia*
Baneberry *Actaea spicata*

Trees:
Scots pine *Pinus sylvestris*
European aspen *Populus tremula*
Common juniper *Juniper communis*
Willow *Salix sp.*
Rowan *Sorbus aucuparia*
Silver birch *Betula pendula*

Pond:
Lady fern *Athyrium filix-femina*
Male fern *Dryopteris filix-mas*
Ostrich Fern *Matteuccia struthiopteris*

WCS design is based on researched recommendations and analysis. The design alternations are meant to benefit WCS usage by moose, thus improving the usage by a variety of animals.

The revision of WCS proposes design alternations aimed at aiding the moose. The WCS dimensions and structural characteristics were kept, as they sufficiently support the species. The design alternations are limited within the middle part of the crossing, where vegetation and ground cover are funnelling animals, ensuring viewing corridors and sufficiently accommodating wildlife.

Moose habitats are added to complement the structural habitat connectivity, creating a more efficient connection.

Existing plants

Added plants

Figure 37 WCS proposal (map source: Google Earth, modified by me)

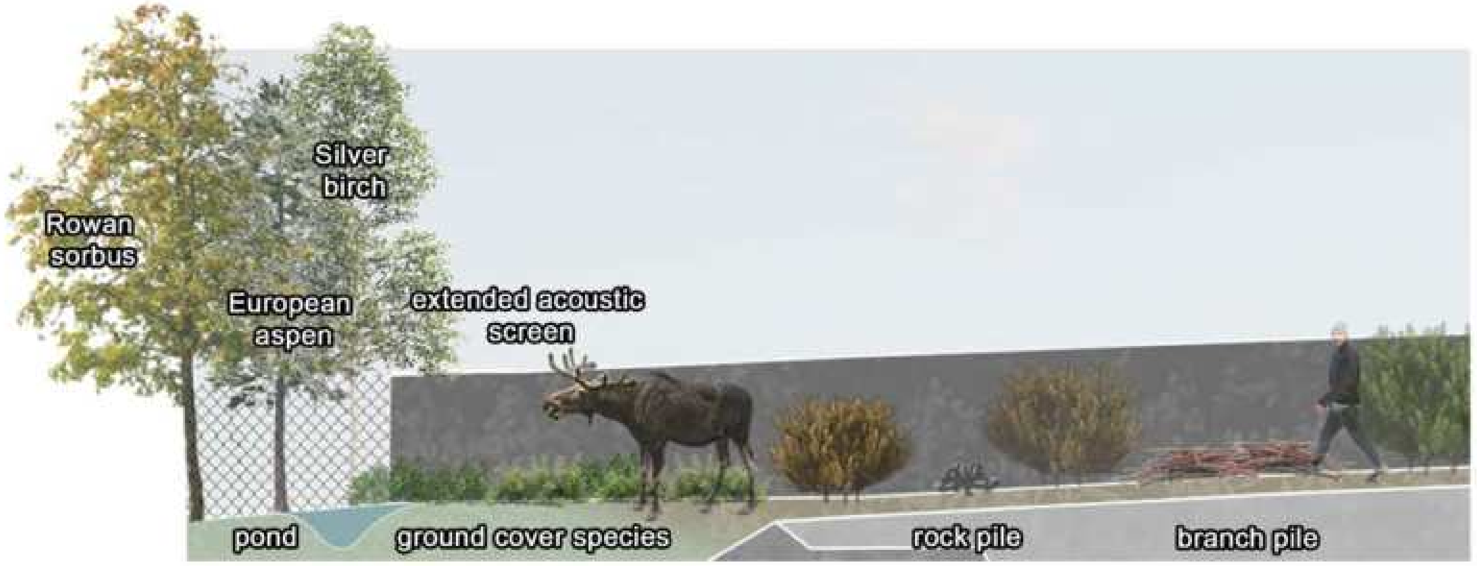


Figure 38 Schematic overpass section, detail

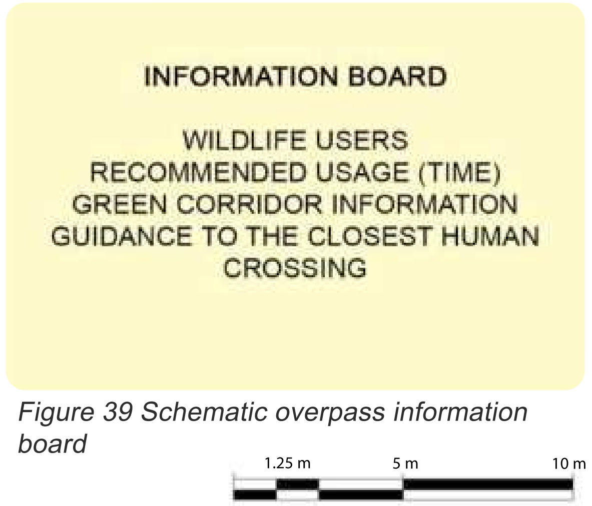


Figure 39 Schematic overpass information board

The design focuses primarily on the entrances to the crossing, as they were identified as the most problematic. Acoustic screens are extended to limit disturbance and pollution. That created an opportunity for the replacement of the old fencing. The new fence segment is buried in the ground to prevent animals from reaching the road lanes.

Vegetation at the entrances was replaced with ground cover species, to create a better clearance. Tree clusters are placed near newly designed ponds with ferns growing around them.

Furniture was added to the crossing in the form of branch piles and rock piles. Branches are replaced in winter with freshly cut twigs to provide forage all year around.

Information boards were installed at both entrances to provide guidelines on recommended WCS usage and details about the species that utilize it.

Figure 40 Schematic overpass section

Figure 41 Inspiration of buried fencing (Mats Lindqvist)

Figure 42 Inspiration of habitat piles (Mats Lindqvist)